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RESPIRATION CURVE FOR McINTOSH APPLES[1]

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A study of respiration by measuring CO_2 output has for some time proven to be a valuable means of diagnosing the storage behaviour of apples. The form of the resulting curve obtained by plotting CO_2 output rates against time, as well as a study of actual rates, and the transition of the curve on change of environment, have contributed valuable data for respiration studies.

The characteristic trend of CO_2 output rates of fruit commences with a rising line shortly after fruit set until a peak is reached about mid-season; then a falling line is evident until harvest, after which another similar rise and fall ensues. Thus the usual complete curve is one consisting of a double hump. The second hump or climacteric is of extreme interest when making a study of storage behaviour.

During the summer of 1936 arrangements were made to study the respiratory rates of McIntosh apples with the primary object in view of determining how closely the senescent respiratory curve conformed to the characteristic trend determined for other fruits. For this purpose a healthy vigorous tree in an apple orchard at Iroquois was selected. The entire crop of one limb on this tree was harvested when the fruit was considered to be at the proper harvest stage for storage. Some of these apples were selected for immediate study and the remainder were placed in storage. Samples of these latter were removed from storage at intervals throughout their storage life in order to establish the trend of respiration under storage conditions.

The temperature at which all CO_2 output records were made was 55° F. This temperature was maintained by immersing the single-apple respiration chambers in a water bath. An air stream free of CO_2 was passed over each apple. After leaving the chamber, the air stream was bubbled through Pettenkofer tubes containing a standardized barium hydroxide solution. These tubes were emptied and titrated daily, and from this the mean hourly rate of CO_2 output of each apple was calculated. Daily records were also made on external observations of the condition of the fruit.

The results of the first year's work indicated that the respiration rates assumed a downward trend from harvest time until the end of storage life. This was contrary to the anticipated results. The expected senescent hump was missing entirely in all trials.

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There were two possible explanations for this phenomenon, either McIntosh did not pass through a senescent hump phase or, if it did, this hump occurred previous to harvest.

For the second year's work the identical source of the fruit as for the first year was used. Instead of waiting until harvest, however, the first sample was picked on August 25. Successive samples were picked on August 29, September 22, and October 5. The last sample was approximately the same maturity as was all the fruit used for the first year's work. All apples were placed in the respiration chambers within 24 hours of picking.

The resulting respiratory curves are shown in Figure 1. It will be seen that the curve for the earliest picked sample (August 25) commences with a slightly ascending line which continues for 8 or 9 days. At this point some of the fruit shows an extremely sharp rise and fall after which a more gradual falling trend is assumed. This latter trend resumes the approximate air line level it assumed previous to the sharp rise. Some of the fruit failed to produce this rise. This absence or reduction of the climacteric in extremely immature fruit was noticed by Kidd and West (2) in Comice pears, but they failed to find it in apples.

The second pick fruit (September 9) assumes an entirely different trend. These apples all produce descending rates which continue for about 10 days after which time ascending rates occur. After a maximal point is reached the rates show a gradual decrease. This descending phase is not nearly as steep as the previous increasing phase. It will be noted also that the hump does not reach as high a maximal point as in the apples of the first pick, but the subsequent trends after the peak are practically the same.

The curve for third pick fruit is not radically different from that of the second pick. There are certain differences, however, in that the third pick starts with a level phase rather than a falling phase, after which the rates increase to a maximal point which is followed by a gradual falling phase. This latter phase is higher than in the first and second pick.

In the fourth and last pick there are produced two types of curves. In one type an initial rising phase occurs, while in the other there is a falling phase which continues throughout. The apples with the falling line approximate the circumstances of the first year's results. Those showing an initial rising line are probably slightly less mature.

Evidently the same curve does not occur on the tree as is represented after the apples are detached. If this were so the initial rates of successive pickings would approximate the curve of the previous picks at the same time. The chief difference to be noted in this regard is that the senescent hump is hastened by detachment. If we wish to approximate the respiratory condition on the three therefore we can only do so at the initial points after detachment from the tree. If these initial points are plotted, the resulting curve would appear as indicated in Figure 2.

Further examination of Figure 1 shows considerable divergence in the minimal values previous to the climacteric rise in the first three picks. What is of interest is that the difference between this minimal rise and the climacteric peak is quite close in all three cases, viz., 11.5, 11.0 and 9.0 mgms. of CO_2 per kgm. hour. The difference that does exist, however, is a tendency for the increasing slope of the climacteric to decrease with maturity.

FIGURE 1: THE RESPIRATORY ACTIVITY OF McINTOSH APPLES REMOVED FROM THE TREE AT DIFFERENT DATES.

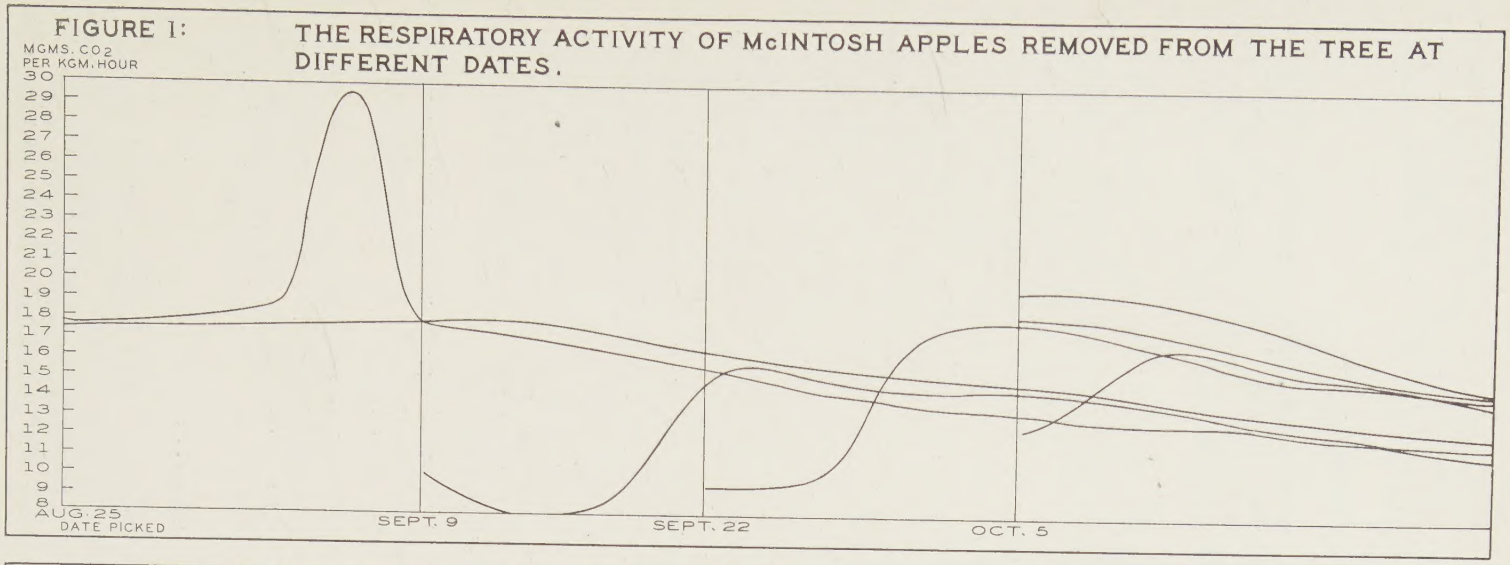
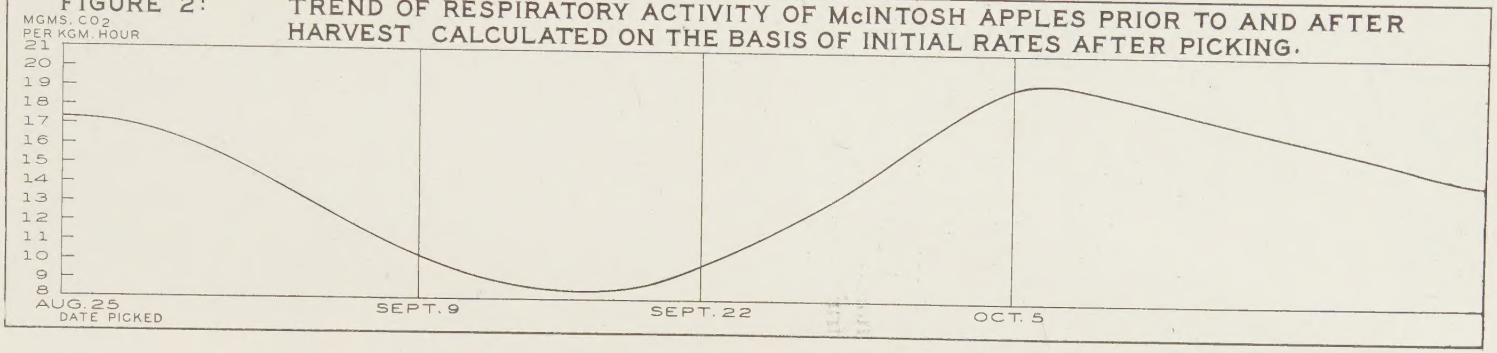


FIGURE 2: TREND OF RESPIRATORY ACTIVITY OF McINTOSH APPLES PRIOR TO AND AFTER HARVEST CALCULATED ON THE BASIS OF INITIAL RATES AFTER PICKING.



If the generation of an auto-stimulant theory of Kidd and West (1) is assumed, it would then appear that the total effect is very nearly equal in all picks. As maturity progresses however, there appears to develop a state of metabolism which tends to oppose the effect of the auto-stimulant.

DISCUSSION

The outstanding conclusion to be made is that a senescent hump or climacteric does occur in McIntosh apples. From this year's work it appears to occur about the end of September. This point coincides with the time when starch is rapidly disappearing and the ground colour is becoming yellow.

On considering the storage behaviour of this variety it would seem that the climacteric phase must be passed on the tree if maximum storage quality is going to be obtained. In other experiments designed to establish a co-relation between maturity and core flush development in storage it would appear that an appreciable reduction in core flush would result from allowing McIntosh to pass the climacteric phase on the tree.

In an experiment (4) embracing the study of methyl bromide as a fumigant for apples, it was found that if fumigation were delayed for several weeks after harvest, less injury resulted as compared to apples fumigated immediately after harvest. Hence it would appear that if the fruit is allowed to pass the climacteric and settle down to a stable state of metabolism, less injury ensues from the methyl bromide fumigant.

It was found in gas storage experiments that McIntosh exposed to a 7% CO_2 and 14% O_2 mixture at 39° F. before reaching the climacteric suffered from CO_2 injury. No injury was found in the same treatment with mature McIntosh apples which would probably be at the same stage as pick 4, at time of harvest. These facts suggest that McIntosh apples have a different degree of susceptibility previous to the climacteric. Kidd and West (3) have shown that a temporary increase in CO_2 output is produced in gas storage in the pre-climacteric phase in certain varieties. This could not influence the concentration in the gas chamber of the previous experiment since the work was conducted in continuous flow gas chambers with ample air flow to take care of this increase.

It can be seen that if the occurrence of the climacteric could readily be determined while the fruit is still on the tree it would be of immense value to the fruit grower in selecting fruit for storage.

An attempt is being made to co-relate ethylene production with the climacteric rise. If the method proves satisfactory, a more suitable means of determining the climacteric may result. From this information, the grower could be more reliably informed as to the proper harvest time for best storage results.

SUMMARY

Respiration studies on individual McIntosh apples at 55° F. revealed only a falling trend during the first year's work. Investigations during the second year's work revealed the fact that the senescent hump in respiration occurs at or just previous to the time of harvest. From experimental

evidence it appears that McIntosh store better and develop much higher quality if the senescent hump phase is passed on the tree. In other experiments it was also shown that if apples were allowed to pass the climacteric phase they were much less susceptible to CO_2 or methyl bromide injury.

REFERENCES

1. KIDD, F. and WEST, C. Report of the Food Investigation Board for the Year 1934, (p. 119).

2. KIDD, F. and WEST, C. Report of the Food Investigation Board for the Year 1935, (p. 85).

3. KIDD, F. and WEST, C. Report of the Food Investigation Board for the Year 1937, (p. 101).

4. PHILLIPS, W. R., MUNRO, H. A. U., ALLEN, C. E., Sci. Agr. 19 : 7-20. 1938.

INVESTIGATIONS ON TRANSPLANTING FRUIT TREES

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The optimum time of year to plant fruit trees has always been a subject for debate among fruitgrowers and nurserymen. However, it has been a debate without conclusive findings, for the facts on the subject have been few and not well established. Pearl's survey (4) of the literature in 1928 served to clarify the issues in regard to transplanting methods and to point out the gaps in our basic knowledge, making it seem highly desirable that our standard practices should be examined in the light of the known physiology of fruit trees and with consideration to nursery procedure.

Experiments in the transplanting of sweet cherry trees had been carried on at the Horticultural Experiment Station, Vineland, a number of years ago and were reported in 1930 (7). These tests had shown the need of similar information for the other fruit trees, and as a result there was started in the fall of 1932 a time-of-planting experiment with the apple, pear, Domestica plum, sweet cherry and peach. The rootstocks used were seedlings of French Crab apple, French pear, Myrobalan plum, Mahaleb cherry and Elberta peach.

PLAN OF EXPERIMENT

The tests on time of planting were carried on for 5 consecutive years in order to get a fair sample of the seasons.[2] Plantings, usually 10 trees of each kind of fruit, were made in mid-October, mid-November, early December, as early as possible in the spring, and early May. Some of the trees for planting at the latter date were dug in April, heeled in and planted about three weeks later. All plantings were made on an area of land classified as Vineland fine sandy loam. The trees were 2 years old except the peaches which were 1 year. Pruning at planting time was about the same as given on most fruit farms of the district, which is the removal of $\frac{1}{2}$ to $\frac{2}{3}$ of the top. Trunk diameter 2 inches above the union was the only measure of tree growth, and was taken at planting time and at the end of the first and second years in the orchard. As the number of trees available did not always allow sufficient selection for uniformity there were frequent size differences between lots planted in a certain season. Errors from this cause were reduced to a minimum by the use of the geometric mean growth rate formula,

$$\frac{\text{Increase}}{(t_2 - t_1)\sqrt{\text{original} \times \text{final}}} \times 100\%,$$

$t_2 - t_1$ (2 years), being a constant in all determinations. No pruning was done except at planting time, and when blossoms developed on the trees they were removed as soon as they could be pinched out without taking away young leaves.

[1] Associate in Research.

[2] Putman and Chapman have given climatological data for southern Ontario. Vineland is in the County of Lincoln. See Sci. Agric. 18 : 401-446. 1938.

When trees for the above tests were dug, additional trees were taken up, pruned, washed free of soil, weighed and planted near the time-of-planting test with the idea of lifting a certain number at intervals during the winter and spring, measuring the weight changes, and observing the development of new roots. By taking special care these trees could be lifted from this soil so that all of the old root system and even most of the tender new roots remained intact.

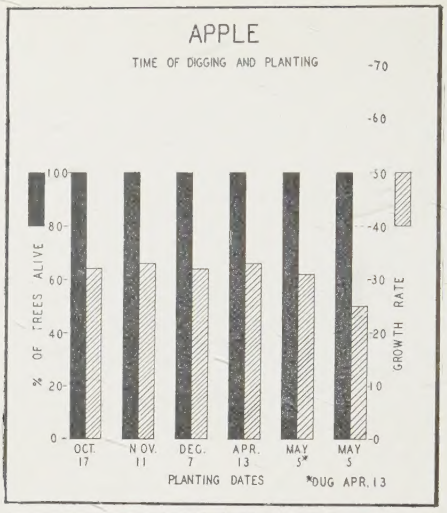
As the time-of-planting tests progressed the need for information on the effects of some practices became evident, and as a result certain supplementary experiments were carried out. Most of these concerned desiccation of nursery trees, and top and root pruning at planting time; these will be discussed under these headings in this paper.

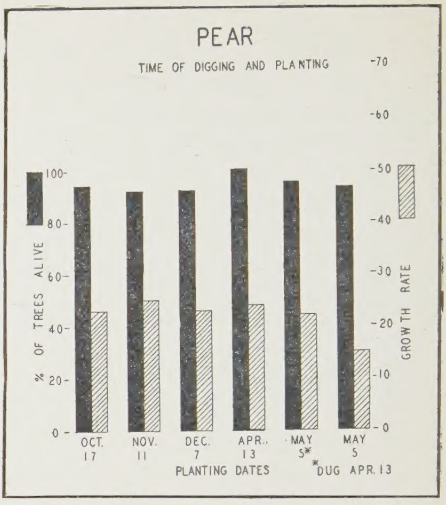
RESULTS

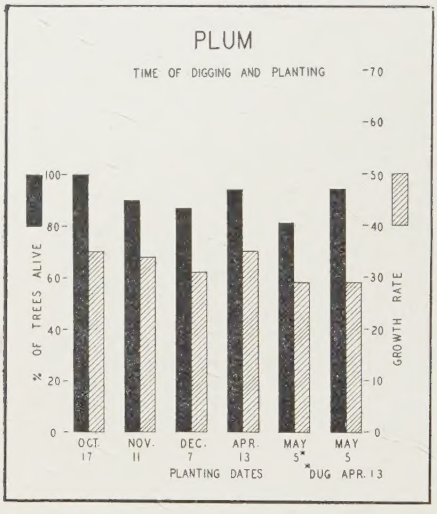
There were marked differences in seasonal results both in stand and growth of trees. However, it is not the purpose to discuss the possible reasons for these differences, but rather to consider what one may expect from certain practices carried on over a period of years. With this thought in mind the data have been averaged for the 5-year period and presented in this way in Figures 1 to 5. In the first 2 years there were no "May dug and planted" trees, in the third year there were no "April dug and May planted" trees, and in the fourth year there were no plum trees. In these few instances of incomplete experiment the probable result had to be estimated from the figures for other years and other kinds of fruit. This was necessary because of the effect of large inter-year differences.

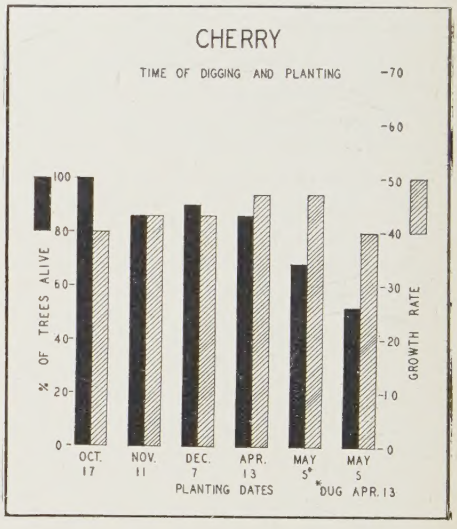
In Figures 1 to 5, the difference in growth rates for the various kinds of fruit trees is the most striking result. The order of decreasing growth rate is peach, sweet cherry, plum, apple and pear, with the first mentioned more than $2\frac{1}{2}$ times the growth rate of the last one. Undoubtedly, these growth rates were influenced by the speed of recovery from the shock of transplanting and are therefore unlikely to be the typical growth rates of established non-bearing trees. Then too the growth rate relations might be quite different on other soil types. Nevertheless it is commonly recognized that under favourable conditions peach trees grow much more rapidly than apple and pear. Dotti (2) mentions the slow start made by newly planted pear trees in Italy.

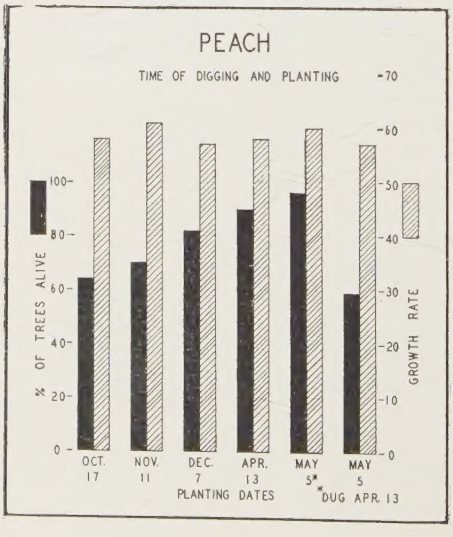
If a stand-growth index to measure transplanting results could be devised, the optimum treatment might be seen more clearly, but the writer knows of no satisfactory means of combining stand and growth figures. However, by having stand and growth results side by side as in Figures 1 to 5, due consideration can be given to each of these measures of response. It can be seen that there is no close relation between stand and growth. In some plantings which resulted in heavy mortality the growth of the surviving trees was quite satisfactory (peach, May dug and planted) and in other plantings in which the growth was poor the stand was average or better (pear, May dug and planted).











FIGURES 1-5. Stand and growth of apple, pear, plum, cherry and peach trees as affected by time of digging and planting in five consecutive years, 1932-1937. Planting dates are also averages for the five year period.

Stand

Throughout these experiments apple trees were a perfect stand at all times which is proof that they transplant readily. In pears there was a 100% stand for the mid-April planting and a light mortality with no appreciable differences at other planting times. With both plum and sweet cherry, October planting gave the best stand of trees but these fruits differed in that late spring digging and planting gave poor results with cherry but fairly good results with plum trees. Fall planting of peaches cannot be recommended for this district because of poor stand of trees. The entrance of the Canker disease (*Valsa cincta*, Fr.) at pruning wounds or other injuries seems to be the main difficulty with fall planted peaches. Often the surviving trees have trunk cankers which result in early death of the trees unless they are thoroughly cleaned out and disinfected. Peach trees planted in the fall of 1936 averaged more than one trunk canker per tree, while spring dug and planted trees had only one canker per 10 trees and these had developed at points where there had been mechanical injuries.

Growth

Except in plums November planting resulted in as good or slightly better growth than October or December planting. Planting as early as possible in the spring, the average date being April 13 in these experiments, resulted in about the same growth rate as the November planting. Peach was the only kind to favour May planting over April planting when the trees were dug in April, and this holds for both stand and growth though it is doubtful if the differences are sufficient to warrant a delayed planting recommendation. Late digging (early May) of apple, pear, plum and sweet cherry trees appears to be inadvisable. On the other hand, peach trees grew well even when dug as late as the first week in May, but as has been pointed out already, the stand was very considerably reduced.

The Best Time to Plant Fruit Trees

After making allowance for the response in both stand and growth the following conclusions seem justified:

1. For plum and cherry, mid-October planting seems to be slightly better than November and December planting but apple and pear show no decided differences in stand or growth attributable to time of planting in the fall of the year.

2. Very early spring planting, *i.e.*, as soon as the soil is sufficiently dry that it will not puddle, gives results very similar to fall planting. This applies to all fruits but peaches, for which spring planting gives best results.

3. Even when the trees are dug very early in the spring and heeled in well, there is usually a reduction in stand and growth by delaying planting until early May. Peaches are an exception.

4. Delayed digging from the nursery row results in still further reduction in stand and growth of trees.

5. Peaches should be planted only in the spring. They should be dug in the fall or very early spring, heeled in well and planted in April or early May. If dug in the fall the tops should not be pruned and adequate precautions should be taken against mechanical injuries to the top.

INITIATION AND GROWTH OF NEW ROOTS AFTER TRANSPLANTING

Numerous investigators have shown that the roots of fruit trees have no true rest period similar to that which occurs in the above-ground parts of the tree, but that root growth continues all winter if the soil temperature remains sufficiently high. Bodo (1) states that root growth of plums and apples occurs at temperatures as low as 2–4° C. and 4–5° C. respectively, and Tanaka (6) gives 4–5° C. as the minimum for peaches and 7–8° C. for apples and pears. Observations at Vineland also indicate that root growth goes on at temperatures not far above the freezing point. It would be interesting to have data on the required temperature for the initiation of new roots on transplanted trees as there is no certainty that this temperature is the same as the minimum for root elongation.

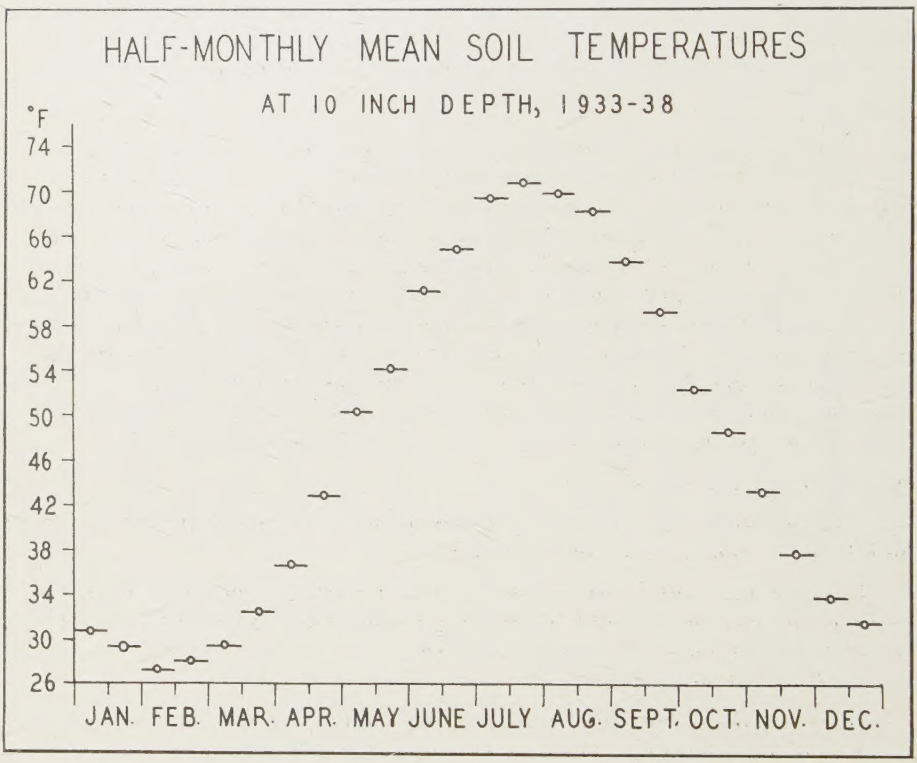


FIGURE 6. Soil temperatures at 10-inch depth taken at 9 a.m. each day, 1933-38, calculated to half-monthly means.

Trees planted at Vineland in October or early November commonly develop a few new roots before the soil temperature becomes too low. A large proportion of these new roots arise just back of the pruning cuts. The same applies to trees dug in the fall and planted in the spring, provided the roots have not been unduly exposed to drying or given a further pruning at planting time. On spring dug and planted trees new roots tend to arise from various points on the old root system, some near the pruning cuts but a good many from points nearer the main axis of the tree. It is likely that a certain proportion of these new roots were initiated in the nursery row

but emerged from the parent root only after the tree was transplanted. Trees planted in December were seldom much ahead of the April planted trees in new root development when examined in May. This result is understandable when the soil temperatures during the winter months are taken into consideration (Figure 6). Because of the low soil temperatures at the ten-inch depth from mid-November to mid-April not much new root growth can be expected in a normal year. However, even the initiation of new roots during this period results in a greater abundance of new roots in the early spring.

TABLE 1.—ESTIMATED AMOUNT (0–20) OF NEW ROOT GROWTH ON FRUIT TREES, MEAN OF THE SEASONS 1935–36 AND 1936–37. ESTIMATE MADE MAY 21.

Time of digging and planting	Oct. 22	Nov. 12	Dec. 12	Apr. 16	May 7
Apple	13.2	16.0	8.8	9.5	0.5
Pear	3.2	2.7	1.1	1.3	0.2
Plum	14.8	15.8	9.1	4.6	0.1
Sweet Cherry	0.9	2.3	2.0	0.5	0.1
Peach	0.5	0.4	0.1	0.1	0

At various times throughout the winter and spring, 3 trees of each kind of fruit were taken up for an estimation of new root growth. Usually roots on plum were the first to appear, but by the latter part of May roots on apple were often just as abundant as on plum or even more so (Table 1). Roots on pear were slower in developing and less plentiful even in late spring, and sweet cherry and peach were still more backward. As the sweet cherry tree develops a considerable leaf surface very early in the spring, and as its new roots are formed slowly it is not at all surprising that many sweet cherry trees are lost from desiccation. The intake of water is probably not nearly fast enough on hot windy days to make up the water deficiency resulting from rapid transpiration from the leaves.

Trees planted in October always commenced new root growth before those planted in November, but by late spring the differences were insignificant. Comparing trees planted in mid-December and in mid-April there was not much difference in new root growth on apple, pear and peach, but the December planted plum and cherry trees were in the lead. No great difference between these lots could be expected since during the interval there were probably only short periods of soil temperatures high enough for root initiation and growth. It is not surprising that there was very little new root growth by May 21 on trees dug and planted just 2 weeks before. Even though at this time the soil temperatures were very favourable for rapid root initiation and growth (Figure 6) it appears that a considerable time is required before young roots push their way through the epidermis of the parent root. As fall and early spring planting tends to retard bud opening, the foliage on trees dug in late spring (early May) is more advanced. It is obvious therefore that trees dug in early May even though planted immediately are at a distinct disadvantage particularly on warm dry windy days when the water loss from leaves is very rapid.

No proven explanation is offered for the slight improvement in stand and growth from heeling in peach trees until early May rather than planting in mid-April. It may be related to more rapid initiation of new roots on the "heeled in" trees than on the planted ones. At least it is common practice to heel in less deeply than to plant. At this time of the year the soil temperatures would be higher near the surface than at lower levels, and thus the "heeled in" trees would have the advantage in the initiation of new roots. If these "heeled in" trees had their root systems left intact, *i.e.*, not pruned, and if they were protected from drying out during planting operations, it is conceivable that they might give slightly better results than trees planted immediately after they were dug in mid-April.

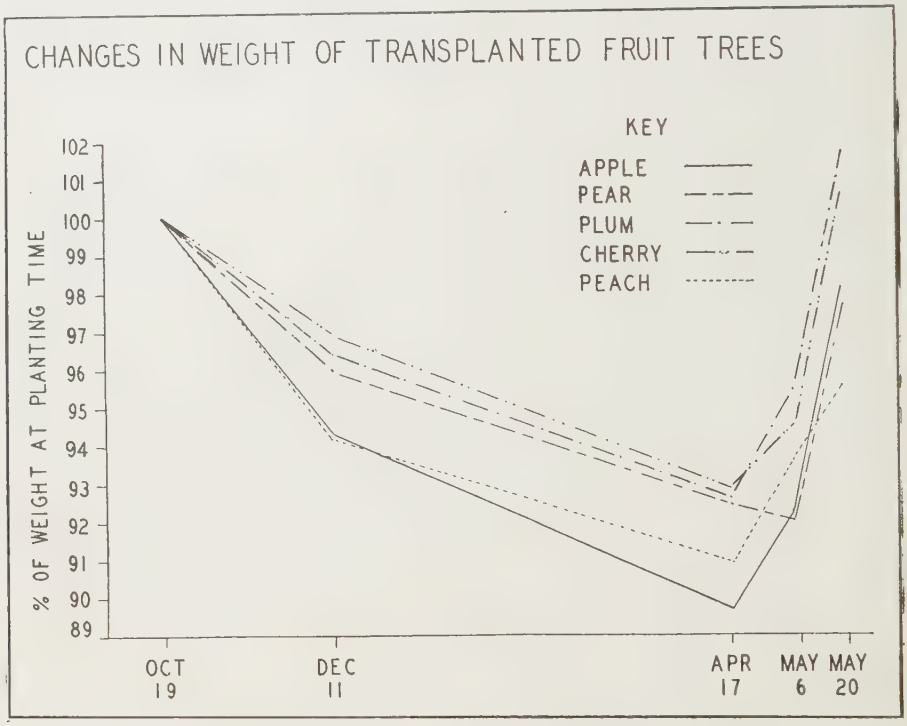


FIGURE 7. Changes in weight of fall planted fruit trees when taken up at various times during the winter and spring, averages for three years.

CHANGES IN WEIGHT OF TRANSPLANTED FRUIT TREES

All trees which were dug at various times during the winter and spring for observations on root growth were weighed at planting time and again at the time the root observations were made. In 3 of the 5 years the dates of weighing coincided fairly closely. The means of these readings on October planted trees expressed as percentage of the weight at planting time are given in Figure 7, the dates given being means for the 3 years. The April 17 readings are not necessarily the low points in tree weight which may have occurred either before or after these dates. However, other records indicate that it is about this time that the tree reaches its minimum weight and begins to increase due to water intake through the roots.

From mid-April to May 20 there was a slow increase in weight of tree, so slow that even with some addition through photosynthesis the trees did not reach their planting-time weight until the latter part of May. The explanation for this slow increase probably lies in the paucity of new roots and the low temperature of the soil. The very considerable loss in weight suffered by these trees was not to any appreciable extent a result of their immaturity at planting time (mid-October) as the more mature trees planted in mid-November lost almost as high a proportion of their planting time weight.

One point worth particular attention is the failure of pear trees to show weight increase until about May 6. As the pear trees had more new roots than either cherry or peach (Table 1) it appears that the explanation may be either a slow intake of water by the old root system or a high rate of water loss from the young leaves. Since on May 6, plum buds had just opened and the buds of other trees were just on the point of bursting, photosynthesis could not have caused any significant gain in weight nor is it likely that respiration caused any appreciable loss in weight which might explain the difference between pears and the other kinds of fruit trees.

DESICCATION OF NURSERY TREES

That nursery trees will dry out quickly on exposure to drying conditions and, provided the root tissues are still alive, will regain their weight rapidly in water or moist soil was shown by some records taken in the fall of 1931. On November 23 ten 2-year apple and ten 1-year cherry trees were stripped of their leaves, washed free of dirt, weighed and left exposed to the air for 66 hours. At the end of this time the apple trees had lost 15% of their weight and the cherries, 17%. All were showing shrivelling of the bark. Five of each kind were planted in moist soil at about 3° C. and the other 5 of each kind were "planted" in water in a tub at about 10° C. At the end of 44 hours these lots were weighed separately and it was found that the trees in water were within 1% and 3% of the original weight for cherry and apple respectively. The lots in soil were still about 6% below their original weight. As there were no new roots and as the water could have entered only through the old root system this represents a fairly rapid intake. These trees were then planted in the field. All of the apple trees grew, making an average terminal growth in 1932 of 43 and 45 inches for the lots in water and soil respectively. On the other hand one cherry tree out of each lot died and the surviving ones made poor growth, averaging 2.6 and 3.8 inches. Experiments on water intake with partially desiccated root cuttings have also shown a very rapid return to normal weight when placed in water or a moist medium. This work has also shown marked individuality between apple seedling rootstocks with respect to rapidity of correction of a water deficit. This may explain in part the differences in speed of recovery following transplanting which are commonly seen in commercial orchards.

The desiccation of the roots of nursery trees would probably cause the most reduction in stand and growth in trees on which new roots were emerging or just ready to emerge from the old roots, *i.e.*, trees which had been heeled in moist soil over winter or for a few weeks in the spring. Part or all of the advantage of having new roots develop soon after setting the tree in its permanent location might be lost thereby.

Vineland records on evaporation covering seven seasons, 1932–1938 inclusive, show that the danger of desiccation of nursery trees is less in the fall than in the spring. On certain days in the fall there will be just as rapid drying conditions as on certain days in the spring, but on the average there is considerably less danger of desiccation in the fall of the year as the following mean daily evaporation figures (inches) show:

April	May	June	July	August	September	October	November*
.08	.09	.12	.16	.13	.10	.06	.05

* First half of month only.

In the exposure of nursery trees it is generally supposed that the root dries out very much more quickly than the top and if so, the water deficit, under ordinary conditions, is probably largely in the roots. In the fall of 1934 certain experiments (Table 2) were carried on which probably desiccated the tops more than the roots. On October 16 some apple, plum, cherry and peach trees were dug, one-half of each kind being completely defoliated by hand before digging and the other half left with all leaves intact. Full summer foliage was on the apple, plum and peach trees at this time but the cherry trees had already lost about two-thirds of their leaves. All trees were heeled in at once, and after 24 hours of normal weather for this season they were taken up and re-weighed.

Table 2.—Desiccation of nursery trees with and without leaves. October 16–17, 1934

—	Treatment	Number of trees	Loss based on original weight
			%
Apple (2 yr.)	A*	5	2.8
	B	5	16.0
Plum (2 yr.)	A	5	1.9
	B	5	16.2
Sweet cherry (1 yr.)†	A	5	0
	B	5	9.6
Peach Seedlings (6 mos. old)	A	5	6.5
	B	5	14.0

* A—Defoliated. B—Leaves intact.
† About two-thirds of the leaves were already off these trees when dug.

In Table 2 is shown the increase in desiccation as a result of leaving the foliage on the trees after digging. By calculation from weights and moisture contents of the leaves only a very small part of the water loss could have come from leaf tissues, nor would respiration account for any considerable weight loss. It is obvious therefore, that most of the loss in weight represented water lost from the tissues of trunk and branch, and indeed the shrivelling of the bark could be seen quite plainly. These trees were not planted in the field, but in some lots treated similarly this same

autumn there was considerably higher mortality among cherry and peach trees which were not defoliated at digging time. On the other hand, apple and plum trees planted November 8 did not show a difference in stand from these two treatments. By this date, of course, the leaves were nearly ready to fall and a marked difference would not be expected. Swarbrick (5) found that apple rootstocks (Malling XIII) transplanted well in early autumn even when the leaves were left intact. Investigations at Vineland show that apple trees withstand the transplanting shock better than any of the other common deciduous tree fruits. Results at Vineland certainly indicate that nurserymen would be well advised to remove all leaves from their nursery trees before digging them.

TOP PRUNING AT PLANTING TIME

Effects on the Growth of New Roots

Heavy top pruning of nursery trees probably reduces the amount of new roots formed during April and early May, and conversely, leaving all or most of the top results in more vigorous development of new roots. There is therefore, immediately after planting, a definite tendency shown towards balancing the top and root. In experiments carried on from 1933 to 1937, very heavy top pruning (trees being cut off 6 inches above the bud union) resulted in very marked reduction in amount of new roots. Removal of buds on the other hand, seems to result in no decrease of new root development and may show an increase in some instances. The results of some observations made in 1936 are fairly typical of the data obtained in other years. Fifteen 2-year pear and fifteen 2-year apple trees were dug and given the following treatments: (1) Unpruned; (2) Unpruned, all buds removed as they were bursting; and (3) Top pruned off 6 inches above the bud union. On May 22, over a month after planting, the trees were taken up and estimates (0–20) of the amount of new roots were made, the mean of the readings being as follows:

Treatments	1	2	3
Apple	12	12	1
Pear	1	.2	0.5

At this time there were numerous rosettes of leaves on the unpruned non-disbudded trees, and they were beginning to make shoot growth. Evidently even up to this time, the leaves were of no benefit in the growth of new roots from the old root system. It is even possible that there is some competition between buds and new roots for the food materials stored in the tree. The stored food lost on bud removal must be a very small part of the total contained in the tree. On the other hand, when branches are pruned heavily there is a considerable loss of stored food and this may explain the reduction in growth of new roots in this case. To summarize the evidence, it appears that, during the first month after transplanting, wood pruning has a depressing effect on new root growth, but the same is not true for bud pruning (disbudding); therefore, from the standpoint of quick recovery from the transplanting shock, disbudding methods of training trees are preferable to wood pruning methods.

Effects on Mortality and Size of Tree

There is ample data to show that the pruning of live wood from established fruit trees results in a dwarfing of the top to a degree in keeping with the severity of the pruning. There is much less definite information on the effects of pruning at planting time. Working with apple trees Oskamp (3) concludes, "It does not appear that the trunk girth has been materially affected by the amount of pruning at planting time." In the Vineland work sweet cherry trees only were used in planting-time pruning experiments, some of which have already been reported (7). In experiments conducted over the 6-year period, 1927–1932, no significant amount of dwarfing resulted from light pruning at planting time, and in fact, the pruned trees were the larger ones at the end of the second year in the orchard in 5 out of the 6 years, though significantly so in one year only (Table 3). Two-year trees were used in the first 3 years and 1-year trees, in the last 3 years. There were 10 to 20 trees under each treatment in each year.

TABLE 3.—EFFECT OF LIGHT PRUNING* AT PLANTING TIME (FALL) ON SIZE OF CHERRY TREE TWO YEARS LATER

	1927	1928	1929	1930	1931	1932
Unpruned	100	100	100	100	100	100
Pruned*†	125	121	106	116	124	98

* Removal of approximately one-third of the top.
† Size relative to unpruned trees given the value of 100.

Experiments at Vineland indicate that fall planted sweet cherry trees may be pruned with safety at planting time, there being no necessity of delaying pruning until spring. No killing back from pruning cuts has ever been observed. Whitten (8) reports similar results and shows that in the fall the water loss is less from pruned than from unpruned trees.

In view of the advisability of training the tree to a desirable form at planting time some top pruning is nearly always demanded. From experimental results available at the present time there seems to be no basis for objection to this pruning on the grounds that it has an appreciable effect in reducing the size of the tree. Either there is no reduction or it is insignificant. Furthermore, such pruning often results in a reduced mortality of the trees (7).

Bud pruning (disbudding), where it can be used, presents some merit from the standpoint of removal of the minimum amount of stored foods for a given reduction in leaf area in the early season after transplanting. Newly planted trees, on which a considerable amount of wood of the previous season's growth is left, usually develop leaf rosettes from most of the buds, making a large leaf area at a time when new roots are few and their water intake is slow. This being a time when the life of the tree is at stake the removal of buds, by reducing the demand for water, offers merit. Results already presented showed that bud removal does not reduce the early development of new roots. Therefore disbudding should be useful in balancing top and root so that mortality is reduced. It might be particularly useful for trees planted late in the spring. Indeed a very

limited test with one year sweet cherry trees planted May 4, 1934, did show this benefit from disbudding. Out of 13 trees not disbudded 7 died, while out of the same number of trees disbudded to 5 buds, only 3 trees died.

ROOT PRUNING AT PLANTING TIME

Pearl (4) has summarized the available information on root pruning at planting time, and his conclusions are that the fibre is unimportant, often being dead at planting time, but that the main roots are important for anchorage and a source for the initiation of new roots. The writer has observed that young roots usually start first from the smaller main or secondary roots rather than from the large ones; therefore the more small roots above fibre size on the nursery tree the greater is the quantity of new roots formed during the winter and early spring. An abundance of new roots is an insurance against death from desiccation on hot windy days.

It is not an unusual practice for growers to prune some or all of the root ends at planting time. If these trees have been heeled in soil over winter or even for a short time in the spring, many new roots will be arising near the cut ends of the old roots and the removal of these ends at planting time would mean a considerable reduction in the number of new roots during the next few weeks. To measure the effect of such root pruning 18 apple, 24 pear, 24 plum and 18 sweet cherry trees were dug in November 1937, heeled in outside over winter and taken up for planting on April 13 (cherry) and April 29 (apple, pear and plum). Previous to planting, each tree was paired with another of approximately the same size. One of each pair had a 2-inch piece pruned away from the ends of all roots and the other one was left unpruned. The growth rates, based on increases in trunk diameter in 1938, were as follows:

	Unpruned	Root ends pruned
Apple	25	23
Pear	22	16
Plum	38	32
Sweet Cherry	17	16

In all four comparisons the growth rates were reduced by root pruning, there being a greater reduction in pears and plums than could be accounted for by the removal of stored food in the few short root ends which were cut away. These results suggest that it is unwise to prune the roots of fruit trees at planting time if such trees have been dug some time previously and held in soil under conditions favourable for the initiation of new roots. Therefore, in nursery practice, it would seem a waste of time and effort to conserve a larger root system on a fruit tree than is likely to be retained by the grower. If a few main roots are unnecessarily long they should be shortened as soon as possible after digging the tree.

DISCUSSION

It has been shown that apple, pear, plum and sweet cherry trees transplant just as successfully in the fall, from mid-October to early December, as in the early spring. Because of the rush of other work in

the spring, planting is often delayed until early May. This delay in transplanting results in appreciable reduction in stand and growth of trees as compared to fall or very early spring planting. In districts therefore where soil and weather conditions are similar to those occurring at Vineland, Ontario, it would be to the nurseryman's own interest to encourage fall planting or very early spring planting, thus reducing replacement costs. Early fall planting, mid-October, may not appeal to nurserymen because the tree is then in full foliage and stripping of the leaves is necessary. Planting in December is hazardous because of the danger at planting time of root injury from freezing. With these objections to October and December planting, November would seem to be the most suitable time in the fall to plant apple, pear, plum, and cherry trees.

For spring planting trees should be dug in the fall or very early spring and well heeled in until the land is ready for planting. Young roots will be starting, though perhaps not to be seen on casual observation, while the trees are heeled in. This advantage will be wholly or partially lost if the roots are pruned or allowed to dry out at the time of planting. Late digging, early May, is likely to result in a poor stand and poor growth probably mainly because the development of new roots is very much retarded.

CONCLUSIONS

1. For the first two years after transplanting fruit trees the order of decreasing growth rates was as follows: Peach, sweet cherry, plum, apple and pear.

2. A poor stand of trees after transplanting was not necessarily correlated with poor growth of the surviving trees, and conversely poor growth was not always correlated with a poor stand.

3. Under Vineland conditions, peach trees succeeded much better when planted in the spring, but fall planting was quite satisfactory for apple, pear, plum and sweet cherry trees.

4. Planting as early as possible in the spring gave results very similar to fall planting. Except for peach trees a delay in planting usually meant a reduction in stand and growth. Delayed digging from the nursery row resulted in still further loss in stand and growth.

5. New roots often developed on fall planted trees before the onset of winter and these continued growth again in the spring before the soil was dry enough for planting. The order of decreasing development of new roots was plum, apple, pear, cherry and peach.

6. Fall planted fruit trees lost from 7 to 10% of their weight by mid-April. At this time all trees but pear began to gain and by May 20 plum and cherry trees had passed their original weight.

7. Desiccation of nursery trees was harmful, particularly when they were allowed to dry out through actively transpiring leaves.

8. On the average, moderate top pruning of sweet cherry trees at planting time resulted in a slight increase in size over unpruned trees.

9. Severe top pruning reduced the amount of new root growth as estimated in the latter part of May.

10. Disbudding did not reduce root growth in the early spring, and there was some indication that it had a beneficial effect.

11. The removal of 2 inches from the ends of the roots of nursery trees which had been heeled in over winter, resulted in a decrease in the growth of the trees.

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REFERENCES

1. Bodo, Fritz. Untersuchungen auf dem Gebiete des Wurzelwashstums des Apfels und der Zwetsche. Fortsch. Landw. 1 (24) : 768-773. 1926.

2. Dotti, F. Potatura della chioma e delle radici al trapianto. Romagna agricola e zootecnica, No. 11–12. 1934.

3. Oskamp, J. The effect of pruning apple trees at planting time. New York (Cornell) Memoir 138. 1931.

4. Pearl, R. T. Transplanting fruit trees. Jour. S. E. Agric. College, 25 : 166-186. 1928.

5. Swarbrick, T. Root regeneration upon transplanted apple rootstocks. Univ. of Bristol Agric. and Hort. Res. Sta. Annual Report for 1929, 40-46.

6. Tanaka, Y. Investigations on the time of transplanting young fruit trees. Agric. and Hort. (Japan), 8, 5. 1933.

7. Upshall, W. H. Some experiments in transplanting sweet cherry trees. Proc. Am. Soc. Hort. Sci., 27 : 259-264. 1931.

8. Whitten, J. C. An investigation in transplanting. Missouri Res. Bul. 33. 1919.

THE POLLINATION OF THE SWEET CHERRY ON VANCOUVER ISLAND, BRITISH COLUMBIA

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INTRODUCTION

Unfruitfulness in the sweet cherry has been noted by many. This condition has been especially prevalent in the small garden where one or two trees have been planted to furnish the requirements of the home. Such trees are normally healthy and full of bloom.

Self-sterility in the sweet cherry has been definitely reported by many investigators. A study in unfruitfulness of the sweet cherry was begun at this Station in 1931 and had as its objects:

1. The verification, for this locality, of the reported complete self-sterility of the sweet cherry.

2. The determination of compatible varieties which, when interplanted, might be expected to give a reasonably good commercial set of fruit.

LITERATURE REVIEW

No attempt is being made to review in great detail the literature having a bearing on the subject. Shoemaker (1) cites 72 references in the preparation of his bulletin which was published in 1928. Tufts and Philp (2), Coe (3), Overholser (4) and other investigators in the Western United States all report the sweet cherry to be self-sterile or nearly so. In rare instances fruit has matured from self-pollinations. The workers, above referred to have also found Bing, Lambert and Royal Ann to be inter-incompatible and Deacon to be a desirable pollenizer for this group of commonly grown varieties. Palmer (5) and other workers have found that Deacon pollen gave satisfactory sets on Bing, Lambert and Royal Ann.

MATERIALS AND METHODS

Twenty-six varieties of sweet cherries (*Prunus avium*) have been grown in the orchards of the Dominion Experimental Station, Saanichton, B.C. Original plantings were made in the spring of 1914 at a distance of 28 feet by 28 feet. At time of planting, varieties were randomized with no attention being given to compatible varieties being planted in correct relation to each other.

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A study of compatibility in sweet cherry varieties began in 1931 using 8 of the most important varieties. Selfing bags were installed in duplicate on varieties being studied, and counts of blossoms and fruit set made. In this way the value of pollen arising from any variety upon its own flowers was determined. Cross-pollinations were carried out using the same type of bag and method, *viz.*, counting blossoms enclosed by the bag and the number of fruit set. A cotton bag, fitted over a wire framework, has been used throughout in these studies. The wire framework is approximately 10 inches in diameter and 16 inches long. When installed on the tree the branch forms an axis passing lengthwise through the centre of the cage where it is held in position by means of free wire ends wrapped around the branch at either end of the cage. The branch selected should be reasonably straight, unforked and of sufficient strength to carry the weight of the bag and cage. The unbleached cotton bag is pulled over the wire framework and tied. This method of isolating flowers has been found most satisfactory, as the amount of interference of the bag with the blossoms is reduced to an almost negligible quantity. Wire frameworks may be installed in early season before the fruitbuds show colour. Later, just before the buds open, flowers are counted, bags pulled on and tagged.

Transfer of pollen is carried out by using flower clusters as a brush. By this method a thorough distribution of pollen is made to the stigmatic surfaces with a minimum amount of injury to the delicate flower parts. Self-pollinations and cross-pollinations are made, (1) when about 50% of the flowers are open and (2) just as the latest flowers are opening. This method brings the two applications from 3 to 4 days apart and has given good results. Large paper bags have been used as pollen supply bags and have been found suitable for the purpose.

Cross-pollinations have been carried out between many of the commercial varieties of sweet cherries including Bing, Lambert, Royal Ann, Black Tartarian, Deacon, Pelissier, Early Rivers and Windsor. Emasculation was not practised in order that labour might be reduced and more pollinations carried out than would otherwise be possible. Injury to the flower parts from emasculation introduces another factor contributing to error.

The practice of collecting and storing pollen against the time when it would be needed has not been followed in these studies. Sufficient bloom is bagged to give an abundance of pollen for the work required. Varieties as pollinizers can only be useful when supplying viable pollen at the moment it is required for transfer to the stigmas of the female parent. The effectiveness of transferring pollen, by means of flower clusters used as a brush, is shown by comparing set of fruit in controlled crossing tests with corresponding results under open-crossing conditions.

Germination tests have not been conducted, but from observations made in the field and from data secured from cross-pollinations there is much evidence to show that an abundance of viable pollen is produced by all varieties.

INFLUENCE OF BLOOMING DATES OF VARIETIES

If varieties are to cross-pollinate freely there must be considerable overlapping of blooming periods. Records for the 10-year period (1929–38) show that considerable overlapping does occur in blooming periods of most varieties, sufficient to insure a supply of viable pollen at the time the pistillate parts of the flower are ready to receive it. Earliest average date of full-bloom occurs in Belle of Orleans and latest average date in Choisy. Unsatisfactory sets could be expected where earliest and latest varieties to bloom were planted together.

In most varieties of sweet cherries the blooming period continues for at least 3 weeks if the reckoning is made from date the first flowers open to the shedding of the last blossoms. This period may be extended to a month in certain seasons where weather conditions retard development of the flowers. Because of climatic conditions, too, dates of blooming may vary as much as 3 or 4 weeks in different seasons. Varieties, however, keep approximately the same order of blooming each season.

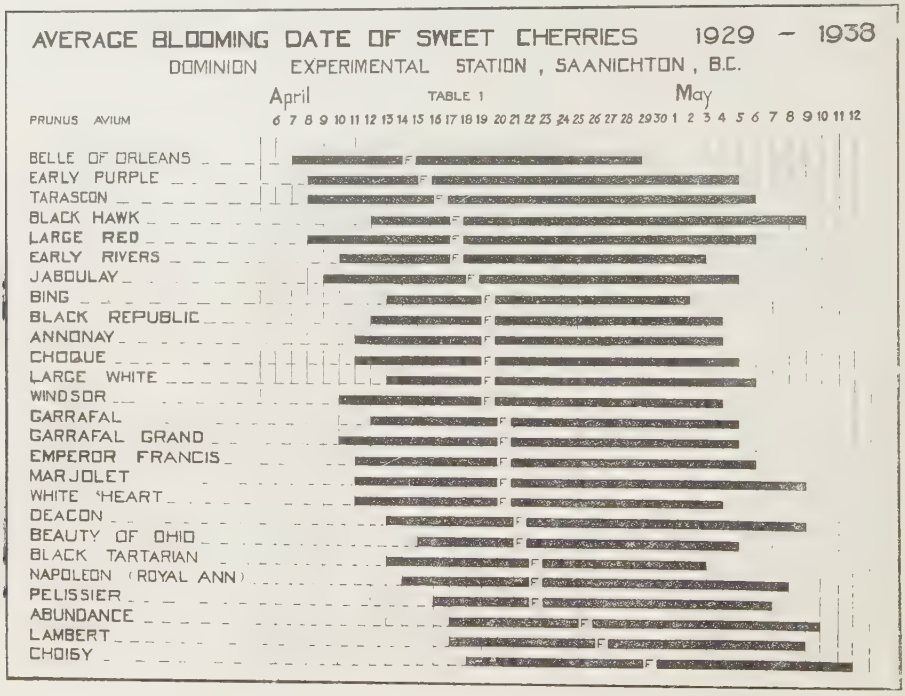

FIGURE 1.

RESULTS

A. Self-compatibility Studies

Complete self-incompatibility exists in all sweet cherry varieties tested. Fruit failed to set in selfing bags on Bing, Black Tartarian, Deacon, Early Rivers, Lambert, Pelissier, Royal Ann and Windsor while open-crossed flowers gave sets ranging from 7.9% in Pelissier to 27.0% in Royal Ann with an average for the 8 varieties of 21.5% set, based on 18,788 blossoms counted. Causes for flowers failing to set and for fruit failing to go on to maturity are outside the scope of this article.

TABLE 2.—PERCENTAGE SET OF SELFED AND OPEN-CROSSED FLOWERS OF DIFFERENT VARIETIES OF CHERRIES

Variety	Years	Flowers	
		Counted	Average set
	No.	No.	%
1. Bing			
× Open-crossed	8	2792	21.3
× Self	5	1595	0.0
2. Black Tartarian			
× Open-crossed	7	2661	36.5
× Self	5	1149	0.0
3. Deacon			
× Open-crossed	8	3297	13.9
× Self	5	5106	0.0
4. Early Rivers			
× Open-crossed	4	1506	16.4
× Self	1	75	0.0
5. Lambert			
× Open-crossed	7	2370	21.7
× Self	5	1426	0.0
6. Pelissier			
× Open-crossed	4	1782	7.9
× Self	1	95	0.0
7. Royal Ann			
× Open-crossed	8	2992	27.0
× Self	5	1196	0.0
8. Windsor			
× Open-crossed	5	1388	20.0
× Self	5	1232	0.0

B. Cross-compatibility Studies

Pollen from 9 cherry varieties has been used on Bing as female parent (Table 3). Of these, Deacon gave a set of 25.8% which is greater than the set received from open-pollinations. Windsor, Black Tartarian and Pelissier pollens have given sets sufficiently large to mark them as satisfactory pollenizers for Bing.

TABLE 3.—EFFECT OF DIFFERENT VARIETIES OF CHERRIES AS POLLENIZERS FOR BING

Variety	Years	Flowers	
		Counted	Average set
	No.	No.	%
Bing:			
× Open-crossed	8	2792	21.3
× Self	5	1595	0.0
× Black Tartarian	6	887	19.2
× Deacon	6	1113	25.8
× Lambert	5	746	0.0
× Montmorency	5	1088	7.6
× Pelissier	4	748	17.3
× Rivers	4	1238	13.9
× Royal Ann	4	794	0.0
× Schmidt	2	465	16.1
× Windsor	5	773	19.8

Black Tartarian has been used largely in these studies as a male parent and as such has given good results. In Table 4, Black Tartarian is marked as a good female parent by sets obtained from open-crosses as well as from those controlled.

TABLE 4.—EFFECT OF DIFFERENT CHERRY VARIETIES AS POLLENIZERS FOR BLACK TARTARIAN

Variety	Years	Flowers	
		Counted	Average set
	No.	No.	%
Black Tartarian:			
× Open-crossed	7	2661	36.5
× Self	5	1149	0.0
× Bing	5	1037	21.3
× Royal Ann	5	1000	24.2

The average set of 13.9% (Table 5) for Deacon under open-crossing conditions is low as compared to sets reported by Overholser and Overley (4) in Washington and is considerably below the average set of 21.3% for all sweet cherry varieties tested. This indicates Deacon as being a low-yielding variety under conditions existing at this Station, which is also in line with actual yields obtained during the corresponding period. The controlled crosses, where Bing, Lambert and Royal Ann were used, gave very low sets marking them as ineffective and unsatisfactory where Deacon was the female parent.

TABLE 5.—EFFECT OF DIFFERENT CHERRY VARIETIES AS POLLENIZERS FOR DEACON

Variety	Years	Flowers	
		Counted	Average set
	No.	No.	%
Deacon:			
× Open-crossed	8	3297	13.9
× Self	5	1506	0.0
× Bing	5	1281	7.0
× Lambert	3	1111	1.5
× Royal Ann	3	1110	5.1

Table 6 shows set obtained from Deacon as being lower than that obtained from open-crosses, while sets from Bing and Pelissier were lower still.

TABLE 6.—EFFECT OF DIFFERENT CHERRY VARIETIES AS POLLENIZERS FOR EARLY RIVERS

Variety	Years	Flowers	
		Counted	Average set
	No.	No.	%
Early Rivers:			
× Open-crossed	4	1506	16.4
× Self	1	75	0.0
× Bing	3	903	12.4
× Deacon	2	751	14.7
× Pelissier	3	1045	10.0

Table 7 shows Deacon to be an outstanding pollenizer for Lambert. Deacon and Pelissier pollens gave sets materially greater than was obtained from open-crossing. Bing pollen failed completely.

TABLE 7.—EFFECT OF DIFFERENT CHERRY VARIETIES AS POLLENIZERS FOR LAMBERT

Variety	Years	Flowers	
		Counted	Average set
Lambert:	No.	No.	%
× Open-crossed	7	2370	21.7
× Self	5	1426	0.0
× Bing	2	375	0.0
× Black Tartarian	5	808	20.0
× Deacon	5	907	37.0
× Montmorency	5	1011	17.2
× Olivet	5	1263	9.2
× Pelissier	4	871	26.6

Open-crossing would indicate that Pelissier (Table 8) is relatively a low yielder. Deacon is again the best pollenizer of those tested giving a set slightly better than was obtained under open-crossing. All pollens tested showed a degree of compatibility.

TABLE 8.—EFFECT OF DIFFERENT CHERRY VARIETIES AS POLLENIZERS FOR PELISSIER

Variety	Years	Flowers	
		Counted	Average set
Pelissier:	No.	No.	%
× Open-crossed	4	1782	7.9
× Self	1	95	0.0
× Bing	4	1721	5.9
× Deacon	4	1243	10.8
× Early Rivers	4	1332	4.4
× Lambert	4	1481	8.5
× Royal Ann	4	1368	6.4

In Table 9, Deacon and Pelissier are shown to be compatible to a marked degree with Royal Ann. Sets from these two varieties are somewhat lower than set obtained under open-crossing conditions but yet sufficiently high to give a satisfactory crop of fruit. Bing and Lambert pollens were completely incompatible on Royal Ann.

TABLE 9.—EFFECT OF DIFFERENT CHERRY VARIETIES AS POLLENIZERS FOR ROYAL ANN

Variety	Years	Flowers	
		Counted	Average set
ROYAL ANN:	No.	No.	%
× Open-crossed	8	2992	27.0
× Self	5	1196	0.0
× Bing	4	766	0.0
× Black Tartarian	6	1220	16.9
× Deacon	6	1124	24.2
× Early Rivers	4	1034	12.1
× Lambert	5	705	0.0
× Pelissier	4	1341	21.4
× Windsor	5	471	11.8

SUMMARY

1. Records (1929–38) show that sufficient overlapping occurs in blooming periods of the varieties under study to insure a supply of viable pollen at the moment the stigmatic surfaces are ready to receive it.

2. An abundance of pollen was produced by all varieties tested.

3. All sweet cherry varieties tested proved to be completely self-sterile.

4. Bing, Lambert and Royal Ann (Napoleon) are inter-incompatible.

5. Table showing the relative pollenizing value of varieties, under test, which have given satisfactory sets when compared with sets obtained under open-crossing conditions:

Female parent	Table	Pollenizing variety		
		1st	2nd	3rd
Bing	3	Deacon	Windsor	Black Tartarian
Black Tartarian	4	Royal Ann	Bing	
Deacon	5			
Early Rivers	6	Deacon	Bing	
Lambert	7	Deacon	Pelissier	Black Tartarian
Pelissier	8	Deacon	Lambert	
Royal Ann	9	Deacon	Pelissier	

6. Deacon is an excellent pollenizing variety.

7. Sour cherry varieties pollinate sweet cherry varieties.

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REFERENCES

1. Shoemaker, J. S. Cherry pollination studies. Ohio Agri. Expt. Sta. Bull. No. 422. 1928.

2. Tufts, Warren P. and Philp, Guy L. Pollination of the sweet cherry. University of California, College of Agriculture. Agri. Expt. Sta. Bull. No. 385. 1925.

3. Coe, Francis M. Cherry pollination studies in Utah. Utah Agri. Expt. Sta. Bull. No. 245. 1934.

4. Overholser, E. L. and Overley, L. L. Cherry pollination studies in Washington for 1930. In Proc. Amer. Soc. Hort. Sci. 27 : 400-403.

5. Palmer, R. C. Cherry Pollination Experiments. Annual Report, Dom. Expt. Sta. Summerland, B.C. 1928.

A FIELD EXPERIMENT ON THE CONTROL OF THE EUROPEAN CORN BORER, *PYRAUSTA NUBILALIS* HUBN., BY *BEAUVERIA BASSIANA* VUILL. II.[1]

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INTRODUCTORY

A field experiment (2) to determine the value of the fungus, *Beauveria Bassiana* Vuill., in controlling the European corn borer, *Pyrausta nubilalis* Hubn., was carried out in 1936 near Chatham, Ontario. The fungus was found to attack the European corn borer in the field, although it failed to reduce materially the corn borer population until late in the season and thus there was little reduction in borer damage in the treated plots of corn. Much greater control was obtained from the application on July 19 than on July 8, a result which indicates that the time of application is an important factor.

In 1937, a second field test of *B. Bassiana* was made. The efficacy of this pathogen was again tested and the importance of the time of application was explored further. The test of 1937 differed from that of 1936 in that all plots were dusted only once and the spores were applied at two rates.

INOCULUM EMPLOYED

The spore inoculum for the field experiments was obtained by rapidly increasing an isolate of *B. Bassiana* Vuill. on soy-bean mash in petri dishes. The fungus was isolated originally from mummified corn borer larvae, and the same isolate was used in the present experiments as in the previous trials (2). A 500 cc. flask culture prepared on July 27, 1936, and kept at room temperature served as the source of inoculum for the initial series of dishes, which were inoculated on May 13, 1937. The spores germinated freely, mycelial growth was rapid, and fresh spores were produced in abundance. In fact, there was no evidence of a diminution in spore production as compared to previous years. The sub-culture was thus nearly 10 months old before the fungus was freshly transferred. Preliminary studies by Timonin and Conners on cultures of *B. Bassiana* received from other workers demonstrated that older cultures were inferior to fresh isolations. This would indicate that cultures of *B. Bassiana* should be transferred at long intervals to avoid loss of vigour and spore-producing ability. A culture from the Centraalbureau voor Schimmelcultures, Baarn, Holland, was atypical and produced spores scantily, while one kindly sent by Lefebvre (1) appeared fairly normal, but spore production was reduced, and the spores in mass were light cream in comparison with the copious deep cream layer of spores in freshly isolated cultures.

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The methods employed in culturing the fungus were only slightly different from those developed by Timonin and described in the previous paper (2). It was found more convenient to soak the soy-beans in a measured volume of water, which was slightly larger than in the earlier experiments, i.e. 250 cc. of water per 100 gm. of dry beans. The excess water was poured off the swollen beans before they were ground, and was added afterwards to the bean mash. This procedure gave a moister mash that could be spread easily in the petri dishes. Spore production was improved by incubating the plates at 25° C. until the mycelium had penetrated the media (about 2 days,) and then placing them on a laboratory bench at room temperature. If the plates were kept for a longer period at 25° C. a luxuriant development of aerial mycelium took place at the expense of subsequent spore production. About one month after inoculation, the plates were sufficiently dry to remove the spores. The total yield of spores was 210 grams from 461 plates, which was more than ample for the experiments. Frequently, more than 0.5 gm. of spores were obtained from one plate, and the average yield was 0.45 gm. per plate, which constituted a marked increase over that of the previous year.

FIELD TECHNIQUE

Spores were applied in the field on 3 days, July 9, July 15, and July 20. On the first day, none of the corn was in tassel; on the second, some of the plants were coming in tassel; while on the third, about half the plants were in tassel and a few in silk. Oviposition had started before the first application was made and by the time of the third, the damage done by the corn borer was noticeable.

The inoculum was prepared by thoroughly mixing spores at the rate of 10 or 40 grams to 16 pounds of white wheat flour. The scheme of applying spores at the 2 rates at the 3 times, together with an untreated series of check plots, is shown in Table 1. The inoculum was dusted with great care from a cheesecloth bag into the throat of the corn plants. It may be of interest to note that this inoculum dusted on the plants on July 9 still adhered abundantly on July 20 after almost continuous rains.

TABLE 1.—TREATMENTS APPLIED TO THE CORN

Treatment number	Grams of spores per acre	Date of application
1	10	July 9
2	40	July 9
3	10	July 15
4	40	July 15
5	10	July 20
6	40	July 20
7	Untreated	

The plots were square and contained 144 hills of the cross-checked corn used in the experiment. The 2 outer rows of hills on all 4 sides of each plot served as a buffer. Fourteen plots formed a block 2 plots wide and 7 plots long. Within each block 2 plots, chosen randomly and independently, were subjected to a given treatment. The blocks, of which there were 10, were contiguous on their long sides and so formed an area, with 7 plots on one side and 20 plots on the other. The labourers who made the counts were each allotted whole blocks so that variability between them would not affect the relative standing of treatments. Also, each operation such as dusting or sampling was carried out on all plots of a block as nearly simultaneously as possible.

The number of borers surviving on a plot was estimated by examining 5 hills. These hills were, of course, chosen randomly from the plot proper of 64 hills, within the buffer previously discussed (2). A first examination was carried out before the autumnal migration, during the period August 30 to September 2, inclusive, and a second during November 2 to 8, inclusive.

PRESENTATION OF DATA

In Table 2, the number per plot of corn borers, by treatments and by blocks, is presented for the counts made in August and in November. The values show the total number of borers surviving in the 10 hills for each treatment at each time. The treatments are numbered as in Table 1.

TABLE 2.—NUMBERS OF CORN BORERS PER PLOT

Block	Treatment No. 1	Treatment No. 2	Treatment No. 3	Treatment No. 4	Treatment No. 5	Treatment No. 6	Treatment No. 7
	At the first count, August 30 to September 2						
1	42	30	35	48	39	27	90
2	43	40	31	44	28	30	109
3	44	71	40	19	31	32	65
4	64	32	46	53	36	38	105
5	56	46	32	36	27	27	85
6	41	28	45	27	28	46	98
7	35	43	39	22	31	35	133
8	24	36	56	34	44	24	110
9	41	24	39	20	39	12	92
10	60	22	28	29	15	7	83
Total	450	372	391	332	318	278	970
	At the second count, November 2 to November 8						
1	50	15	14	26	30	30	81
2	78	37	42	30	24	19	129
3	66	28	51	24	28	50	83
4	19	17	14	13	8	9	31
5	32	18	22	16	32	28	50
6	40	32	34	24	26	23	71
7	56	41	63	54	59	36	73
8	44	46	66	24	45	31	96
9	40	36	55	56	35	40	95
10	58	29	45	24	68	39	103
Total	483	299	406	291	355	305	812

DISCUSSION OF RESULTS

The control due to a given treatment has been calculated as the relative magnitude of the number of borers by which plots subjected to that treatment fell short of the number on plots subjected to no treatment (No. 7 of Table 1). This control was expressed as a percentage of the number on plots held as a control (Treatment No. 7). The percentage control effected by the various treatments at the time of the August and November examinations is presented in Table 3.

TABLE 3.—REDUCTION OF POPULATION EFFECTED BY VARIOUS TREATMENTS

	Treatment No. 1	Treatment No. 2	Treatment No. 3	Treatment No. 4	Treatment No. 5	Treatment No. 6
	%	%	%	%	%	%
At first count in August	54	62	60	66	67	71
At second count in November	41	63	50	64	56	62

From the results shown in Table 3, it can be seen that the treatments Nos. 2, 4 and 6, which consisted of the application of spores at the rate of 40 grams per acre on 3 days, each gave a slightly better control than treatments Nos. 1, 3 and 5, which consisted of the application of spores at the rate of 10 grams per acre on corresponding days. A more marked effect was, however, produced by the time of applying the spores as can be seen by comparing the results for treatments 1 and 2, applied July 9, with those for treatments 3 and 4, applied July 15, or with those for treatments 5 and 6, applied July 20. The importance of the time of application had been suggested by the results in 1936. The work of 1937 indicates that the best time for the application has not been found, but that it probably is later than July 20, since improvement is apparently continuous from July 9 to July 20. The work of 1936, in only touching the extremes of this range of dates, did not preclude the possibility that the best time for application lay within the range.

The results of 1937 differ radically from those of 1936 in that there was no improvement in control between the first and second counts. This difference may be related to the difference in the seasons, for the earlier was rainless whereas during the July of the later season rains were of almost daily occurrence. The promptitude with which the control took effect in 1937 suggested that it might be of value in affording an immediate protection for the corn crop, rather than be only of value in effecting an ultimate reduction of the corn borer population. The ultimate value was the only one appearing from the work of 1936.

SUMMARY

Work done in 1937 was a continuation of work done in 1936 on testing the value of the fungus, *Beauveria Bassiana* Vuill., against the European corn borer, *Pyrausta nubilalis* Hubn. The new work again showed that the time of application of *B. Bassiana* is of the greatest importance and is worthy of further investigation. The rate of application of spores is not of great importance. The full control effected by the fungus was prompt in 1937, in contrast to 1936, when it was delayed until October. In both years, a control of 60% or 70% was ultimately effected.

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REFERENCES

1. LEFEBVRE, C. L. Preliminary observations on two species of *Beauveria* attacking the corn borer, *Pyrausta nubilalis* Hubner. Phytopath. 21 : 1115-1128. 1931.
2. STIRRETT, G. M., G. BEALL and M. TIMONIN. A field experiment on the control of the European corn borer, *Pyrausta nubilalis* Hubn., by *Beauveria Bassiana* Vuill. Sci. Agr. 17 : 587-591. 1937.

IMPROVEMENT OF CROSS-FERTILIZED CROPS—STRAIN BUILDING[1]

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While the majority of perennial grasses and legumes are generally regarded as being cross-fertile, there is ample evidence of wide variations in this respect, both between species and between individuals within certain species. Consequently, in the improvement of these crops the breeding procedure must be varied as required by the nature of the material being worked with. The methods which the breeder adopts in any particular case will depend primarily upon the fertility relationships of the material with which he is working and the nature of the objective which he hopes to attain.

The application of the selfed line method to the breeding of normally cross-fertilized species usually results in a loss in vigour of growth. Nevertheless, this procedure often provides the most direct and effective means of obtaining, in a relatively homozygous condition, certain desirable characters of rare occurrence in the species. The possibility of restoring vigour by controlled mating or random crossing of the resulting lines is a problem which may have to be dealt with when this procedure is followed.

Procedures which involve selection within selfed lines and subsequent hybridization have been widely and successfuly applied to corn breeding. However, in many respects, the corn plant lends itself particularly well to this procedure and there is, as yet, little evidence to indicate that similar methods may be applied with equally satisfactory results to the improvement of cross-fertilized grasses and legumes.

The possibility of isolating self-fertile single plant lines which may be increased without serious loss in vigour should not be overlooked in the improvement of forage crops. In such cases the selfed line procedure may be employed to advantage in the improvement of certain species which are known to consist of mixtures of self-fertile and self-sterile lines.

However the comparatively wide range of variation in plant type, and in the physiological response of plants to certain environmental conditions, which may be observed in many cultivated species of perennial grass and legumes, suggests that considerable improvement may be effected by the application of relatively simple methods which do not aim at genetic homozygosity, but simply at increasing the percentage of desirable type plants in the mixture. In the Improvement of *Dactylis glomerata* Stapledon (9) has succeeded in greatly increasing the percentage of desirable type plants by mass selection. The degree of improvement which is possible of attainment by this procedure depends chiefly upon the genetic constitutions of the individuals which are chosen as a foundation of the

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strain. Mass selection, as a method of improving cross-fertilized species, is probably of greatest value as a means of taking advantage of ecotypes which have become relatively homozygous, with respect to certain characters, as a result of natural selection. This was the method employed in producing Grimm (Sask. 451), a hardy selection of *Medicago media*. In discussing the origin of this strain by mass selection, Kirk (4) says: "Comparative tests amply justify the conclusion that acclimatization by natural selection has been an important factor making for greater hardiness in Grimm alfalfa and in producing a strain (Sask. 451) of superior yielding power for conditions such as obtain in Saskatchewan."

The principle of the selection of individuals to conform to certain standards and the subsequent combination of the chosen plants to form a composite strain is, however, capable of development into a much more refined procedure for the improvement of cross-fertilized plants than is generally practised in ordinary mass selection. Certain modifications of the mass selection methods, as applied to perennial grasses, have been described by Jenkin (2).

STRAIN BUILDING

The term "strain building" has been used by Jenkin (3) to describe any one of several breeding methods which are employed in the improvement of cross-fertilized crops. Kirk (5, 6) regards the term "strain building" as applicable to any system of mating by which a strain is built up by the crossing of carefully selected plants. In our own plant breeding work this term has been used in a much more restricted sense to describe specifically the complicated and refined methods of selection outlined by Jenkin (2). According to this usage of the term, strain building involves the composite crossing of a number of parent plants which were carefully selected on the basis of type and breeding behaviour. The aim is to maintain vigour by bringing into the strain a reasonably large range of genotypes, while at the same time approaching a state of homozygosity with respect to the genetic factors that govern the particular qualities or characters which formed the basis of the provisional selection of the parent material. The term "strain building" may be thought of as a modified method of mass selection, which, in addition to selection on the basis of type or of a certain physiological response to a particular environment, provides for a thorough exploration of the genetic constitution of the provisionally selected plants and a final selection of parents on the basis of their breeding behaviour.

While the application of the strain building procedure provides a relatively new approach to the improvement of cross-fertilized plants, the method itself is not new. The success of many notable livestock breeders can be attributed not only to their ability to select rigidly to a certain type, but primarily to the practice of selecting exceptional individuals on the basis of progeny tests. This is precisely the procedure followed in strain building, as applied to cross-fertilized crop plants.

PROCEDURE

The procedure employed in strain building may best be understood by a consideration of concrete examples which illustrate the various steps involved from the selection of provisional parent material to the production of the composite strain. These have been chosen to include certain varia-

tions in procedure necessitated by differences inherent in the species themselves, as well as in the particular characters which have formed the basis of selection in each case.

Agropyron cristatum

The object in this case is the production of a higher yielding, taller growing strain of the diploid type. A number of individual plants were selected from increase fields of the Fairway variety. These were broken up and several plants started from each in the greenhouse. The clones were later transplanted to the field nursery, so that each original selection is now represented by a row of spaced plants.

During the second year selfed seeds were obtained from plants in each row. The individual selections varied widely in the amount of selfed seed produced. Out of more than 150 selections, only 5 produced an abundance of seed when selfed.

Single plant progenies were grown from about 50 of the selections. Nearly all of these progenies contained many undesirable type plants, and with few exceptions showed marked loss in vigour. Many of the L_1 seedlings in certain lines were albinos. In two cases over 50% of the seedlings lacked chlorophyll and died shortly after emergence. In a few of the progenies, however, albino seedlings did not appear and the L_1 plants appeared vigorous and relatively uniform. The L_1 progenies which showed wide segregation and marked loss in vigour behaved similarly in the L_2 and succeeding generations, and likewise the L_1 lines which appeared strong, vigorous and uniform continued to produce relatively uniform and vigorous progenies in succeeding generations.

On the basis of the results obtained in the progeny tests, 5 of the more promising lines were chosen as parent material. The chosen few were then grown in isolated composite plots under conditions which appeared to be most favourable for random pollination. Two distinct and separate procedures have been adopted in the combination of parent plants in this species. First the L_1 progeny plants from each of the 5 lines have been planted in a composite plot isolated by distance and natural barriers. Secondly, the originally selected plants have been combined in a similar manner. While the first of these two methods is likely to result in a higher percentage of brother-sister mating, it also provides an opportunity for further selection by the elimination of undesirable segregates before the plants are combined to form the composite strain.

The relative value of this strain will be determined when data from comparative strain tests become available. In the meantime, however, an effort is being made to locate additional exceptional breeding parent plants which may be added to those already chosen or which, by reason of superiority, may replace some of the parents which were used in the above strain. At the same time the original parent plants are being subjected to closer scrutiny. By means of dialell crossing and top crossing an effort is being made to learn something of their combining ability. New selections will be subjected to similar tests as they become available.

Melilotus alba

Almost without exception the cultivated varieties of biennial, white blossom sweet clover are strong, vigourous growing types which show rela-

tively little loss in vigour due to inbreeding. As a result of selfed line breeding in *Melilotus alba* at Saskatoon, during the past 15 years, more than 500 single plant lines have been isolated and tested. Much of this material was selected from the variety "Arctic", which has proven superior to most other varieties under western Canadian conditions. This variety which originally was reasonably uniform has, through natural crossing over a period of years, been changed noticeably and now exhibits a much wider range of variability than formerly. Because of this, selection was begun a few years ago with the object of isolating typical "Arctic" plants and reconstituting the variety as nearly as possible in its original form.

Seed of the Arctic variety was sown in isolation to provide a source from which to make selections. This material has been grown in spaced rows and the plants within the rows have been thinned to a distance of 3 feet apart to facilitate selection. From plantings of this kind, from 20 to 100 plants have been selected annually. In this case no absolute standard of selection was established except that leafiness, fineness of stem, disease resistance and hardiness were major considerations.

Selections were made in the second year of growth and each selected plant was entirely enclosed by a large cotton selfing cage, as described by Kirk (7). The cages were used in preference to selfing bags because much larger quantities of selfed seed could be obtained from each plant by this method. A progeny of at least 60 plants was grown from each selection, the following year, and selfed line breeding has been continued in some cases to the sixth and seventh generations. A large number of the single plant lines have been discarded on the basis of results obtained from these breeding tests. About 20 lines have appeared sufficiently promising to carry into the seed increase and strain test phases. Of all the single plant lines tested to date, not one has proven superior to the parent variety in yield of forage and hardiness. One of the most surprising results of this work has been the high degree of uniformity exhibited by many of the first generation lines.

The results obtained from inbreeding sweet clover indicates that in the matter of yield particularly the loss in vigour, resulting from inbreeding, while relatively small, has been sufficient to reduce the productivity of the new lines, as compared with the parent variety. It was decided, therefore, to attempt to combine these better lines, which were chosen on the basis of their breeding behaviour, into a composite strain. Fortunately a reserve of selfed seed was available from each of the original selections and this has been used to establish a composite isolated plot from which seed will be harvested in bulk. The 20 strains were planted in a manner which, it is believed, will encourage cross-pollination to a high degree. Seed will be harvested in bulk from this plot and will be utilized for increase in order to obtain a supply of seed, which can be used in laying down comparative strain tests.

Medicago media

The most conspicuous result of the application of the selfed line method of breeding alfalfa, as reported by Kirk (5, 6), was a marked reduction in vegetative growth and seed production. This procedure resulted in more than 70% sterility in the second generation and, in many families, complete

sterility in fourth generation plants. In the same experiments the average vigour of growth of 65 fourth generation families, as measured by yield of plants, was reduced to only 54% of the parent variety. After 4 generations of inbreeding autogamous alfalfa plants, Kirk (5) found the average yield of herbage to be reduced by 46% and the average seed yield reduced by 78%. These results indicate that, as a method of improving alfalfa, selfed line breeding presents many difficulties.

More recently work was begun which aims at the development of a highly self-fertile, self-pollinating strain of alfalfa through the application of the strain building procedure. Provisional parent plants were selected on the basis of high seed yield. In addition to the autogamous selections described by Kirk and White (8), which were taken from an increase field of Grimm (Sask. 666) grown at the University of Saskatchewan, numerous additional plants have been collected from increase fields of alfalfa throughout various areas.

Experience has shown that fields in which seed setting is unusually poor frequently contain occasional plants which carry a heavy set of seed. When plants of this type are found they are transplanted to the greenhouse and subjected to careful observation and tests to determine whether the exceptional seed yield was due to favourable environment in the field or whether it is an inherent characteristic. The more promising plants are then multiplied vegetatively and later transplanted in an isolated, composite plot in the field, or are subjected to controlled cross-fertilization.

Eight of the autogamous plants described by Kirk and White (8) have been combined by a process of controlled mating into a composite strain at the Division of Forage Crops, Central Experimental Farm, Ottawa. Results of comparative strain tests conducted by Armstrong (1) in 1936 show this composite strain to be equal to the standard varieties in yield of forage and superior in yield of seed. Further tests are being conducted with this strain to determine whether seed and forage yields are maintained in subsequent generations.

DISCUSSION

The examples which have been given of the methods which are being used in the breeding of crested wheat grass, sweet clover and alfalfa, while varying in details of procedure, embody the essential features of the strain building method. The term "strain building" is obviously used by Jenkin (2, 3) in a very broad sense, but if it is to connote a method which is essentially different from mass selection, selfed line breeding, or straight hybridization, it will be necessary to adopt a definition which indicates a definite procedure of plant breeding, especially appropriate in the improvement of cross-fertilized crops. It would appear that there is justification for the term "strain building" in that it suggests the essential nature of a method which is now being followed by many plant breeders with considerable success.

Strain building may be said to differ from mass selection in that the parent plants, entering into the strain, are selected on the basis of their breeding behaviour. This may consist of a simple progeny test or more

elaborate and refined methods of determining the relative value of individuals as parent material. Ways and means of evaluating the original selections which are to form the basis of the new strain is certainly a very important feature of the strain building method.

Strain building differs also from the selfed line method of breeding in that the latter presupposes several generations of inbreeding until the plants have reached a more or less homozygous condition, whereas in strain building the homozygosity is a secondary consideration, except in those qualities which are to characterize the new strain.

There is also a somewhat different concept behind strain building and what we might term straight hybridization. In the latter, two or more individuals are crossed and selections made from successive hybrid generations, with a view to obtaining something quite definite in the nature of a finished product. Strain building, on the other hand, should be thought of rather as a continuous process, whereby better parent material is being uncovered from time to time, and the new strain is being reconstituted with the best parental material then available.

When all is said and done, strain building bears a very close resemblance to the methods which have been followed by the most successful animal breeders. These have had to depend largely on the progeny test for their information. They have placed great value on the exceptional individual as a means of raising the general level of the herd. In the breeding of cross-fertilized crops exactly the same procedure may be followed with equal success and even greater success, when it is considered that it is possible to work with much larger numbers and to discard ruthlessly without the economic disadvantages with which the animal breeder has to contend.

SUMMARY

Cross-fertilized species of crop plants exhibit wide variations in breeding behaviour and fertility relationships. In the improvement of these species the breeding methods which are likely to be most successful will be determined by the nature of the plant material, with respect to these facts, and by the objective which the breeder hopes to attain.

The term "strain building" is suggestive of a method which involves the combination, through random crossing or controlled mating, of a number of parent plants which were selected provisionally on the basis of type or a particular response to certain environments and subsequently subjected to various tests to determine their breeding behaviour, on which the final selection of parent material for the strain is based.

This method of breeding permits of progressive improvement through the uncovering of superior parent plants from time to time and the use of these exceptional plants in reconstituting the strain. An essential feature is the preservation, for all time, of the parent plants which enter into the strain.

The strain building method, as illustrated by the examples given, involves essentially the same breeding procedure as has been employed so successfully in animal improvement for more than a century.

REFERENCES

1. Armstrong, J. Unpublished report, Division of Forage Plants, Central Experimental Farm, Ottawa, 1937.

2. Jenkin, T. G. The method and technique of selection, breeding and strain building in grasses. Imperial Bureau of Plant Genetics: Herbage Plants. Bulletin No. 3. 1931.

3. Jenkin, T. G. Some aspects of strain building in herbage grasses. Report of the Fourth International Grassland Congress. 1937.

4. Kirk, L. E. Alfalfa production in Saskatchewan. University of Saskatchewan Agri. Extension Bulletin, No. 26. 1924.

5. Kirk, L. E. The progeny test and methods of breeding, appropriate to certain species of crop plants. Am. Nat. 67 : 515-531. 1933.

6. Kirk, L. E. Improvement of pasture grasses and legumes. Spragg memorial lectures on plant breeding. Michigan State College. 1937.

7. Kirk, L. E. Methods employed in the breeding of biennial sweet clover (*Melilotus*) and brief notes on the breeding of lucerne (*Medicago sativa*), brome grass (*Bromus inermis*) and slender wheat grass (*Agropyron tenerum*). Imperial Bureau of Plant Genetics: Herbage Plants, Bulletin No. 7. 1932.

8. Kirk, L. E. and White, W. J. Autogamous alfalfa. Sci. Agr. 13 : 591-593. May, 1933.

9. Stapledon, R. G. Methods applied to cocksfoot grass (*Dactylis glomerata*) and remarks as to technique in general. Imperial Bureau of Plant Genetics: Herbage Plants. Bulletin No. 3. 1931.

A STUDY OF THE ENERGY REQUIRED FOR MAINTENANCE, EGG PRODUCTION, AND CHANGES IN BODY WEIGHT IN THE DOMESTIC HEN

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INTRODUCTION

Basal heat production in the domestic fowl has been quite extensively reported upon. However, very few attempts have been made to determine the energy required specifically for the production of eggs, for maintenance, and for changes in body weight in the mature female. Such determinations have, besides their purely theoretical importance, indispensable significance for investigations into the economical aspects of poultry keeping. The present paper will concern itself with the theoretical portion of total feed requirements of mature hens, for purposes of total maintenance, for production of eggs and for changes in body weight. The economical application of such theoretical information will be reserved for a subsequent communication.

For the purpose of securing estimates of the relative weight of the above mentioned fractions of total feed requirements in fowl, application of Fisher's (9) arrangement for determination of partial correlations and partial regressions was resorted to in statistical analyses of carefully secured data on birds kept under conditions approaching the normal state except for the limitations noted below.

Since Benedict, Landauer and Fox (2), Mitchell, Card and Haines (11), Diakow (7), and Axelsson (1) have reviewed the literature pertaining to this subject both recently and thoroughly, the authors propose to refer to the work of other investigators only as need arises.

MATERIAL

Available for this study were the weekly determinations of feed consumed, body weight, and individual weights of all eggs laid for each of 93 Barred Plymouth Rock females through the greater part of their first laying year. Body and feed weights were secured in gm. during the morning hours of the weekly weighing day. Eggs were weighed singly every day. These birds were maintained in batteries of single bird cages from November 8, 1934 and experimental records were obtained from December 6, 1934 to September 19, 1935. The birds were fed an all-mash ration composed of equal parts of a commercial mash and scratch grain, the latter finely ground and thoroughly incorporated with the mash. In addition the birds had free access to oyster shell and tap water. Cod liver oil was incorporated to the extent of 0.5% of the total feed. Chemical analysis and digestibility, using Diakow's (7) and Axelsson's (1) tables for the latter determinations, were as follows:

ANALYSIS OF FEED

	Chemical gm.	Digestible gm.	Heat production per gm. Cal.	Total heat production Cal.
Water	10.13			
Protein	17.75	13.50	5.574	75.249
Fat	4.50	3.79	9.461	35.857
Nitrogen free extract	58.41	49.21	4.183	205.845
Fibre	4.80			
Ash	4.81			
Total calories per 100 gm. feed				316.951

The calorific value of this feed to fowl was, according to this calculation, approximately 3.17 calories per gm.

Through several years the authors had perfected their feeding technique and found that the feed waste during two actual determinations amounted to $1.79 \pm 0.217\%$. Since such waste was deemed rather unimportant, and moreover varied for individual birds from week to week no further account has been taken of this factor, and determinations of weekly feed consumptions have therefore been accepted as obtained. However, efforts to obtain accurate determinations of oyster shell consumption proved unsuccessful. It is a commonplace that the amount of calcium present in feed materials of a predominantly cereal nature is barely sufficient for ordinary body requirements and that the advent of egg laying with attendant deposition of calcium on the egg membrane is paralleled by elevation of blood calcium and consumption of extra-feed calcium. When this additional calcium could not appear in the feed utilization equation it became imperative to eliminate therefrom its counterpart, namely, the egg shell. As the weight of shell had not been obtained on the eggs from these birds an empirical value for the calculation of shell percentage had to be adopted. For this purpose we selected the mean value of 9% shell obtained on the eggs from a pen of similar birds maintained on identically the same regimen which was accorded the present population. Egg weights are therefore henceforth to be understood as the original weights less 9% for shell.

PROCEDURE

When estimates of the energy expended for maintenance, egg production, and changes in body weight are to be considered we are obviously seeking solutions of the equation $y = b_1x_1 + b_2x_2 + b_3x_3$ where y = total feed consumption, x_1 = body weight, x_2 = weight of egg production and x_3 = the weight of change in body weight. The three b values are partial regression coefficients. Through these the respective experimentally obtained weights are transposed into their proper and valid fractions of y. For the purpose of obtaining comprehensive conceptions of the b values, these were determined for 5 periods throughout the experimental year, avoiding records that were in any respect dubious. Thus, January, February, and March were ruled out as were the 4 weeks from June 19 to July 7 in which the feed determinations were not entirely reliable. In

order to avoid chance fluctuations and errors as much as possible the records for 2 weeks were averaged for each one of the 5 determinations. Hence the periods chosen were December 13 to 26, April 4 to 17, May 16 to 29, July 25 to August 7 and August 22 to September 4, thus covering as far as possible the experimental year. From the statistics, relative to each point, the partial regression and partial correlation coefficients were obtained. The various coefficients and their standard errors are presented in Table 1.

CORRELATIONS

The partial correlation coefficients indicate that the 3 characters, size of body, volume of egg material produced, and weight of change in body weight are significantly and positively correlated to the amount of feed ingested. However, the relationship of egg production to change in body weight is always negative. This signifies that the observed measures of feed consumption were inadequate in these birds for storage of body reserves whenever rate of egg production exceeded some critical limit. It will be noticed that these birds exhibited mean gains in body weight during December and late August periods. It therefore becomes obvious that, taking the means of productions into account when pituitary activity did not stimulate rapid ovulation sufficient for a production greater than approximately 200 gm. egg material per week, consumed feed became partially stored as body reserves. Inversely, when ovulation progressed at a rate above this approximate limit, body reserves tended, either directly or indirectly, to function in support of egg production. It will be noticed, however, that the relationship is much more uncertain in the latter event than in the former. That is, it was much less certain in these birds that utilization of body reserves would support egg production, than it was that accumulation of such reserves and production of eggs tended to inhibit one another. The partial correlation of body weight to egg production shows that there did not seem to be any relationship at all between the size of a bird and the total weight of its production. That is, larger and smaller birds had about equal chances to be good or poor producers. When it has been shown that body reserves constitute a somewhat uncertain source for support of egg production, then the feed to egg relationship tends to be a direct one and the size of bird becomes relatively unimportant in this connection.

MAINTENANCE

Having determined the partial regression coefficients and being in possession of the experimentally observed mean values for feed consumption, body weight, weights of egg production, and of changes in body weight, it is possible to analyse these relationships through the use of equation.

$$\bar{y} - y = b_1(\bar{x}_1 - x_1) + b_2(\bar{x}_2 - x_2) + b_3(\bar{x}_3 + x_3)$$

which in its reduced form becomes

$$\bar{y} = c + b_1\bar{x}_1 + b_2\bar{x}_2 + b_3\bar{x}_3$$

when

$$c = y - b_1x_1 - b_2x_2 - b_3x_3$$

If we take the hypothetical case of a bird having throughout the year a constant body weight of 2.4 kgm. and a constant egg production of 200 gm. egg material per week, we get for maintenance requirements through the year the values set out in Table 2.

It will be seen that total maintenance requirements as determined in this analysis fluctuate substantially in the same manner as basal heat production according to Brody, Funk and Kempster (4). The high values representative of the metabolic rate of the somatically not yet fully mature organism is followed by the low levels of April or May. Subsequently a rise occurs during the remainder of the laying season. Dukes (8) found the same elevated metabolism in 13-month-old birds as did Brody, only Dukes' determination was made in November as against Brody's in June. It would therefore appear unlikely that this latter rise in metabolism is due either to increased speed of production or to a seasonal effect. Gerhartz (10) and Mitchell and Haines (12) found a higher metabolism in laying than in non-laying birds, and while it appears to be rather obvious that a rise in metabolism must be due to a more active thyroid gland, the question still remains, why and in what way does the functioning ovary influence the thyroid, and why is it that this influence is most noticeable at a time when ovarian activity is slowing down? These problems are being further investigated.

Titus (14) determined the maintenance requirements for White Leghorn pullets weighing on the average 1632 gm. to be 64.0 gm. per day or 39.2 gm. per kgm./24 hr. during July. In view of the fact that these birds were maintained in pens with adjoining run yards and thus were practically unrestricted in activity, this finding seems to be in good agreement with our determination on caged birds.

Brody, Funk and Kempster's (6) coefficient of 0.30 gm. feed for the maintenance of one unit of 0.73 power of live weight works out at 36 gm. feed per kgm./24 hr. This figure, being an average for the full year is about 5 gm. higher than the average of our determinations. As these authors complain about heavy feed waste and relatively poor housing conditions, the agreement to the determinations by the present authors and to those by Titus is probably as good as could be obtained.

Southgate (13) determined maintenance in the fattening cockerel to require 22.1 calories per sq.m./hr. or 39.15 calories per kgm./24 hr. This represents but 40% of the values for total maintenance presented by the authors, by Titus, and by Brody for laying birds. It amounts to about 53% of the resting metabolism for hens as determined by Diakow (7) and to about 70% of the basal heat production for cockerels found by Brody, Funk and Kempster (4). It must therefore be concluded that total maintenance requirements in cockerels are radically lowered during fattening, or that Southgate's indirect method of determination has not been entirely reliable.

Using the mean of the total maintenance and basal metabolism values presented in Table 2 and Diakow's (7) value of 72 cal. per kg./24 hr. for resintg metabolism we may roughly estimate requirements for work of digestion and for activity as follows

Cal. per kgm./24 hr.

Total maintenance	Resting metabolism	Basal metabolism
Bird and Sinclair	Diakow	Brody
98	72	58

26 Activity

14 Work of Digestion

FEED REQUIREMENTS FOR EGG PRODUCTION

Having determined the necessary amount of feed in gm. for maintenance of one kgm. body weight for 24 hours through the 5 periods of the year we may proceed, in the same way, to secure estimates of the required weight of feed for the production of various volumes of egg material through the same 5 periods. Table 3 gives an abbreviated quotation of such estimates.

Of the 3 production weights the 6 gm. per day is the equivalent of one egg per week of size 19.5 ounces per dozen, and 52.5 gm. per day equals the production of 7 eggs per week of size 24.5 ounce per dozen. From the combined information presented in Tables 2 and 3 it will be possible to obtain estimates of any desired feed consumption within the limits of error attached to the partial regression coefficients. Effects of any shift in body weight may be estimated directly from the pertinent partial regression coefficients.

We may now briefly inquire into the comparative efficiency of the hen and the cow as producers of nutriment for human consumption. The nutritive part of a 56.7 gm. egg contains approximately.

	Yolk	White	Total
	gm.	gm.	gm.
Water	8.14	30.4	38.54
Protein	2.58	4.34	6.92
Fat	5.46	.007	5.47
Ash	.18	.021	.20

The nutritive part of such an egg therefore contains by calculation approximately $(6.92 \times 5.574) + (5.47 \times 9.461) = 90.32$ calories or 1.75 calories per gm. The digestible nutrients in the feed were calculated to contain approximately 3.17 calories. Now the mean of the partial regression coefficients through the year for feed required per gm. of egg material is 0.8753 and the efficiency wherewith the hen utilizes her feed for egg production is therefore given by the equation.

$$\frac{1.75}{3.17 \times 0.8753} = 0.63$$

That is, 63% of the feed which specifically supports the production of egg material is being utilized for this purpose. This is identical with the 62% efficiency for milk production in cows found by Brody and Procter (5). The efficiency of these birds through the five periods was

December	74%
April	63
May	57
July	64
August	60

DISCUSSION

For 5 periods throughout the year we have presented estimates of the energy required for maintenance, egg production and change in body weight for a population of Barred Plymouth Rocks. The question arises, how applicable is this information to other strains and breeds? Surveying the information on basal metabolism met with throughout the literature it becomes strikingly evident that difference between breeds does not enter into the problem as a deciding factor. Determinations of basal heat production values ranging all the way from 47 to 62 calories per kg./24 hr. are met with. These determinations were made on Barred and White Plymouth Rocks, Rhode Island Reds, White Leghorns, Bantams and Wyandottes and various Mid-European breeds and crosses, with no indication of breed differences. In fact Diakow (7) states that no breed difference was found in this respect between the European breeds on which he determined basal metabolism. For the present then it may be said that no breed difference does exist, and that such a difference will, in all probability, not be demonstrable when account is taken of the several sources of variation that occur within each and all breeds.

Furthermore, Brody and his associates (3) find for warm blooded animals ranging in body size from mouse to horse and beef cattle, and including poultry, that the values of the constants A and k in their regression equation 3 (b)

$$Q = Am^k$$

where Q and m represent basal heat production and mass of body respectively, gives this equation the expression

$$Q = 70.4m^{.734}$$

with an average deviation of 10.3%. Taking into account that the body weights included in the data of these authors range all the way from 0.016 kgm. to 800 kgm. it is gratifying to observe that their variations are found to be of the same order as those found between all basal metabolism determinations for poultry throughout the literature, and in our data for maintenance and for egg production between the various points through the laying year. We therefore conclude that the partial regression coefficients for maintenance, egg production, and changes in body weight which have been presented in this study probably have general applicability for fowl kept under conditions similar to those accorded our birds.

CONCLUSIONS

1. Partial correlation coefficients show that, in the ratios indicated by the coefficients, the weight of ingested feed is positively and significantly correlated to weight of the body that is to be maintained, weight of egg material that is being produced, and to weight of change in body weight.

2. Requirements for maintenance decline from values indicative of the high immature metabolism to their lowest values during April and May. Through the remainder of the year there is again a steady rise in metabolism.

3. In the somatically immature bird the efficiency wherewith feed is utilized for purely egg production purposes is about 75%. Through the remainder of the year subsequent to reaching somatic maturity this efficiency drops to about 60%, which is of the same order as that reported in the literature for milk production in cows.

4. The partial correlations between change in body weight and egg production are negative in all instances. They are on the borderline of significance through periods in which losses in body weight occur, but highly significant and of practical value when gains in body weight obtain. Body reserves are therefore drawn upon with little certainty in the support of egg production, whereas the storing up of such reserves actively inhibits the formation of eggs.

5. The partial correlation coefficients show that the total weight of the weekly egg production is independent of body size.

6. The relationships that have been demonstrated for one breed probably hold for most other breeds.

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REFERENCES

1. Axelsson, J. Der algemeine Nährwert (Energiewert) unserer gewöhnlichsten Futtermittel für Hühner Annalen der Landwirtschaftlichen Hochschule Schwedens 4 : 131. 1937.

2. Benedict, F. C., Landauer, W. and Fox, E. L. The physiology of normal and Frizzle Fowl with special reference to the basal metabolism. Bull. 177, Storrs Agric. Exp. Sta. Conn. 1932.

3. Brody, S. and Associates. Growth and development. XXIII. Relation between basal metabolism and mature body weight in different species of mammals and birds. Res. Bul. 166 : 89. Agric. Exp. Sta. Univ. Missouri. 1932.

4. ———, Funk, E. M. and Kempster, H. L. Age changes in the heat production of chickens as measured by a graphic method. A preliminary report. Poultry Sci. 11 : 133. 1932.

5. ———— and PROCTER, R. C. Growth and development. XXXV. Energetic efficiency of milk production and the influence of body weight thereon. Res. Bul. 222. Agric. Exp. Sta. Univ. Missouri. 1935.

6. ————, FUNK, E. M. and KEMPSTER, H. L. Growth and development. XLIV. Energetic efficiency of Egg Production and the influence of live weight thereon. Res. Bul. 278. Agric. Exp. Sta. Univ. Missouri. 1938.

7. DIAKOW, M. J. Untersuchungen über verdaulichkeit Stoff-und Energiewechsell bei Huhner als Grundlagen für die rationelle futterung des Geflügels. Wiss. Arch. f. Landw. Arch. f. Tiernahr. u. Tierzucht. 7 : 571. 1931–32.

8. DUKES, H. H. Studies on the energy metabolism of the hen. J. Nutrition, 14 : 341. 1937.

9. FISHER, R. A. Statistical methods for research workers. Sixth ed. Oliver and Boyd, London. 1936.

10. GERHARTZ, H. Untersuchungen über die Energieumsetzungen des Haushuhns Disert. Bonn. 1914. Quoted after Diakow.

11. MITCHELL, H. H., CARD, L. E. and HAINES, W. T. The effect of age sex and castration on the basal heat production of chicken. J. Agr. Res. 34 : 945. 1927.

12. ————————, and HAINES, W. T. The basal metabolism of mature chicken and the net energy value of corn. J. Agr. Res. 34 : 927. 1927.

13. SOUTHGATE, B. A. The maintenance requirement of the fattening cockerel with a note on a proposed new method for the determination of the surface area of birds. J. Agric. Science, 20 : 206. 1930.

14. TITUS, H. W. The gross maintenance requirement of White Leghorns. Poultry Sci. 8 : 80. 1929.

TABLE 1.—OBSERVED WEEKLY MEAN VALUES FOR FEED CONSUMPTION, BODY WEIGHT, WEIGHT OF EGGS (—SHELL) AND OF CHANGES IN BODY WEIGHT, PARTIAL CORRELATION COEFFICIENTS AND PARTIAL REGRESSION COEFFICIENTS

	December 13–26	April 4–17	May 16–29	July 25–Aug. 7	Aug. 22–Sept. 4
			Mean Values		
y	768 ± 19.1	850 ± 20.3	832 ± 18.0	773 ± 17.6	777 ± 20.2
x_1	2852 ± 44.7	3289 ± 53.9	3237 ± 56.7	3156 ± 52.6	3118 ± 52.9
x_2	81 ± 11.5	289 ± 7.4	253 ± 8.1	213 ± 10.1	172 ± 11.1
x_3	+44 ± 7.1	−6 ± 6.4	−5 ± 4.8	−21 ± 5.2	+7 ± 7.6
			Partial Correlation Coefficients		
$ryx_1 \quad x_2x_3$	+.6985 ± .0543	+.4905 ± .0805	+.6410 ± .0625	+.4087 ± .0883	+.3189 ± .0953
$ryx_2 \quad x_1x_3$	+.6075 ± .0669	+.5481 ± .0742	+.5710 ± .0714	+.4464 ± .0849	+.7281 ± .0498
$ryx_3 \quad x_1x_2$	+.6014 ± .0677	+.6346 ± .0633	+.4044 ± .0887	+.4853 ± .0811	+.6292 ± .0641
$rx_2x_3 \quad yx_1$	−.4371 ± .0858	−.1916 ± .1022	−.1659 ± .1031	−.2460 ± .0996	−.4077 ± .0884
$rx_1x_2 \quad yx_3$	−.2278 ± .1005	+.0016 ± .1060	−.2959 ± .0967	−.1030 ± .1046	−.0850 ± .1053
			Partial Regression Coefficients		
b_1	.2190 ± .0677	.1283 ± .0200	.1645 ± .0206	.0890 ± .0291	.0832 ± .0259
b_2	.7481 ± .2642	.8720 ± .1477	.9669 ± .1457	.8665 ± .1515	.9234 ± .1231
b_3	1.1265 ± .4095	1.4564 ± .1603	1.0180 ± .2413	1.1590 ± .2919	1.3823 ± .1790

y = Feed consumption, x_1 = Body weight, x_2 = Weight of egg production, x_3 = Change in body weight, b_1 = Regression of body weight on feed, b_2 = Regression of egg production on feed and b_3 = Regression of weight of change in body weight on feed.

TABLE 2.—FEED REQUIREMENTS

——	Total feed per wk.	200 gm. eggs per wk.	Total maintenance			Brody's basal heat production per kgm. 24 hr.
			Per 2.4 kgm. per wk.	Per kgm. 24 hr.		
	gm.	gm.	gm.	gm.	cal.	cal.
December	707.2	149.6	557.6	33.19	105	62*
April	667.3	174.4	492.9	29.34	93	52
May	648.2	193.4	454.8	27.07	86	55
July	718.9	173.3	545.6	32.48	103	60†
August	735.2	186.5	548.7	32.66	104	62†

* This value represents Brody's four to seven months level.
† These points are extrapolated from Brody's figure III.

TABLE 3.—WEIGHT OF FEED REQUIRED FOR VARIOUS WEIGHTS OF EGG PRODUCTION PER DAY

Weight of production, gm/day	December gm.	April gm.	May gm.	July/Aug. gm.	Aug./Sept. gm.
6	4.49	5.23	5.80	5.20	5.54
30	22.44	26.16	29.01	26.00	27.70
52.5	39.28	45.78	50.76	45.49	48.48

ECONOMIC ASPECTS OF POULTRY KEEPING IN CANADA WITH SPECIAL REFERENCE TO EGG PRODUCTION

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INTRODUCTION

In the foregoing paper (1) the present authors recorded data on the energy required for maintenance and egg production in caged fowl. It was shown that during 5 periods through the year, namely in December, April, May, July/August and August/September, maintenance requirements for each period amounted respectively to 33.19, 29.34, 27.07, 32.48, and 32.66 gm. of feed per kgm. body weight per 24 hr. The feed required for production of the contents of eggs through the same 5 periods amounted to 0.7481, 0.8720, 0.9669, 0.8665, and 0.9234 gm. of feed per gm. of the nutritive parts of an egg, and for changes in body weight were required 1.1265, 1.4564, 1.0180, 1.1590, and 1.3823 gm. of feed respectively for each gm. of change in weight.

The low value of the partial regressions of eggs on feed indicate the comparatively small moisture content of feeding stuffs, *i.e.*, 10% as against the 75% water in the contents of eggs, which is in the normal range of moisture content of soft animal tissues.

We may now utilize these determinations to clarify various problems on the economics of egg production.

RELATIVE FEED REQUIREMENTS FOR VARIOUS EGG SIZES

In Table 1 we have compared the feed cost for the production of large and small eggs. The 42 and 52 gm. nutritive parts of eggs employed in this table represent respectively one egg each of grades 19.5 and 24.5 ounces per dozen.

Table 1.—Feed required for large and small eggs

Periods	Weight of feed required for production of 52 gm. Nutritive parts of eggs	Weight of feed required for production of 42 gm. Nutritive parts of eggs	Difference
	gm.	gm.	gm.
December	38.9	31.4	7.5
April	45.3	36.6	8.7
May	50.3	40.6	9.7
July/August	45.1	36.4	8.7
August/September	48.0	38.8	9.2
Average			8.78

Table 1 shows the feed required for eggs only. By the help of our standards considerations of feed requirements for maintenance and for changes in body weight may be taken care of as entirely separate entities. Between the two grades there is an average difference through the year of 8.78 gm. feed per egg or an average difference in feed cost of 1.756 gm.

or 4.3% feed per egg for every one-ounce-per-dozen difference in the size of eggs. For a dozen eggs this difference will therefore be 21.1 gm. or $\frac{3}{4}$ of one ounce in feed. This difference is small in itself, and as it is in direct proportion to the amount of egg material it supports it would seem of little importance to the poultry keeper whether his birds laid large or small eggs. However, the feed required by a bird for maintenance of a given body weight remains constant irrespective of the size of egg which that bird produces. This overhead cost of egg production will therefore be proportionately smaller for production of large eggs as reflected in a heavier consumption of feed utilized for egg forming purposes. Furthermore, the prices of various grades of eggs decline at a more rapid rate than do weights of eggs. Small eggs therefore are a misfortune.

INTERRELATIONSHIP OF MAINTENANCE AND EGG PRODUCTION REQUIREMENTS

The next step is to determine how the maintenance of various sizes of birds and various levels of production affect the cost of egg production. For this purpose Table 2 has been set up in which combinations of large and small body weights with high and low levels of production are shown. Production of 6 gm. nutrients of eggs per day is equal to one egg per week of grade 19.5 ounces per dozen, and 52 gm. per day equals production of seven eggs per week of grade 24.5 ounces per dozen.

TABLE 2.—FEED REQUIRED FOR MAINTENANCE AND EGG PRODUCTION PER DAY

	Total feed required for maintenance and production				Per cent of total feed required for production				Per cent difference in total feed between	
Body weight	1.5 kgm.		3.0 kgm.		1.5 kgm.		3.0 kgm.		c − a	d − b
Egg production per day in gram	6	52	6	52	6	52	6	52	6	52
	gm. a	gm. b	gm. c	gm. d	%	%	%	%	%	%
December	54.3	88.7	104.1	138.5	8.3	43.9	4.3	28.1	62.9	43.9
April	49.2	89.4	93.2	133.4	10.6	50.7	5.6	34.0	61.5	39.5
May	46.4	90.9	87.0	131.5	12.5	55.3	6.7	38.2	60.9	36.5
July/Aug.	53.9	93.8	102.6	142.5	9.6	48.0	5.1	31.6	65.3	41.2
Aug./Sept.	54.5	97.0	103.5	146.0	10.2	49.5	5.4	32.9	62.0	40.3
Means	51.7	92.0	98.1	138.4	10.2	49.5	5.4	33.0	62.7	40.3

It will be seen how larger birds, on account of their greater body weight, at comparable levels of production, utilize smaller percentages of their total feed for eggs than do smaller birds. Furthermore, the percentage of total feed cost utilized for productive purposes is near the vanishing point with near minimum production, or in other words, at this point practically the whole feed cost is overhead, *i.e.*, maintenance. The feed cost of the small bird shown in Table 2 at maximum production will not, for these reasons, be as great as that of the large bird at minimum production. The smallest possible bird giving maximum production is therefore the most desirable combination for the achievement of the highest level of economy.

CORRELATION OF BODY SIZE TO TOTAL WEIGHT OF PRODUCTION AND TO SIZE OF EGGS

It has been argued that a small bird will not have the same capacity for heavy production as will a large bird. However, we have shown (*loc. cit.*) that as body weight is not correlated to total weight of production, and as loss in body weight does not support production of eggs to any appreciable degree, consequently the feed-to-production relationship is a direct one uncomplicated by body size.

It has also been argued that small birds have a tendency to lay small eggs. As the number of eggs required to make up the same total weight of production differ by $4\frac{1}{2}\%$ with each one-ounce-per-dozen difference in size of egg the small bird would, in the first place, have a hard task producing enough small eggs to make up this difference. In the second place, she would produce a large number of eggs of undesirable size for market purposes. To elucidate this point we first investigated the egg sizes produced by the White Leghorn and Barred Plymouth Rock populations in the 1935–36 Canadian Egg Laying Contest. The three standard grades of eggs were distributed as follows:—

	W.L. %	B.P.R. %
Large	75.4	75.8
Medium	18.6	19.1
Small	6.0	5.1

showing no difference between the small and the heavy breed.

Furthermore, we analysed this relationship at 5 periods through the year in the data for 93 Barred Plymouth Rocks from which our various statistical standards were derived. The simple correlation coefficients between body weight and egg size were found to be as follows:—

		December	April	May	July/Aug.	Aug./Sept.
r	=	+0.426	+0.167	+0.146	+0.173	+0.209

The 5% point for 92 degrees of freedom comes at 0.203. The August/September coefficient therefore is just within the significant limit though of small practical utility. On the other hand, the December value is not only highly significant but of important magnitude. It is apparent, then, that in the not yet fully grown bird the ovary and oviduct develop somewhat proportionately to body size. However, when the soma of the bird is fully developed, ovary and oviduct have attained their ultimate capacity independently of body size. Total weight of production as well as size of egg are both within limits expressions of inherited characters. They are both, as shown, largely independent of body size in mature birds of the breeds treated, between breeds as well as within a breed. Our theoretical conception of the smallest possible bird at maximum production of standard sized eggs being, economically, the most desirable unit, is therefore supported in fact.

It would, in this connection, be of value to analyse how far down the scale of body size this lack of correlation of body development to egg size holds. It appears obvious that somewhere there must, for purely anatomical reasons, appear an important correlation between the two characters, as indeed the bantam breeds of fowl would indicate. Unfortunately, we are at present, for lack of experimental data, debarred from undertaking such an analysis.

PRACTICAL APPLICATION

Feed Cost

In the following we shall attempt to analyse how these fundamental observations apply to the practical economics of poultry keeping.

During the 3 years from 1933 to 1936 a total number of 10,608 birds were entered in the Dominion Government Egg Laying Contests. The yearly average production was 179.5, 186.5 and 187.7 with an unweighted mean for all years of 184.6 eggs per bird. This figure then represents the average production of the pullet populations from about 1000 breeders' plants approximately evenly distributed all over Canada. We are probably justified, therefore, in assuming that it closely represents the average production level of well kept pullets throughout the Dominion. The 140 Barred Plymouth Rocks and 130 White Leghorns entered in the Canadian Contest for 1935–36, the records of which were used in this study, had average productions of 185.5 and 187.1 eggs respectively. These two populations are probably therefore as good samples of the well kept Canadian pullet universe as may be obtained.

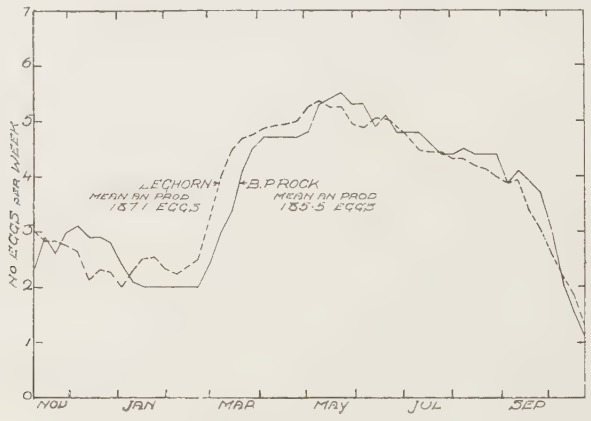

FIGURE 1.

The curves showing the mean number of eggs produced per week by these two populations are presented in Figure 1. From the weekly weighings of contest eggs we were able to calculate the total weight of eggs and so calculate, by the help of interpolated values of the regression coefficients, the required amount of feed for the production of the mean number of eggs of the observed sizes.

In the contests, body weights are not secured weekly, and we were therefore unable to determine the actual maintenance requirements of these birds. However, this is immaterial in so far as we are not concerned

with any specific case but rather with observations that will serve to show the general course and scope of events. As samples of body weight we therefore chose determinations from experimental flocks. The smoothed body weight curves for the Barred Plymouth Rocks and White Leghorns employed are presented in Figure 2.

FIGURE 2.

From the weekly determinations of body weights in these curves, and by the help of interpolated values of our maintenance standards and regression coefficients for changes in body weight we calculated the feed requirements for maintenance and for changes in body weight. These values then will serve to illustrate the approximate requirements for fairly large and small birds. These determinations which are shown in Table 3 are probably closely representative of the average requirements of pullets kept under conditions similar to those of our experimental birds.

TABLE 3.—FEED REQUIRED FOR MAINTENANCE, CHANGES IN BODY WEIGHT AND EGG PRODUCTION BY LARGE AND SMALL BIRDS

Feed required for	White Leghorns		Barred Rocks		Difference
	gm.	lb.	gm.	lb.	%
Maintenance	22752	50.2	34649	76.5	41.5
Changes in body weight	−7		662	1.4	
Egg production	8553	18.9	8553	18 9	
Total	31298	69.1	43864	96.8	33.4

The interrelationship of the weekly determinations are shown in Figure 3.

The reasons for the negative amount shown in Table 3 for changes in body weight in the White Leghorns will be readily understood from Figure 3. Feed required for the small gain in body weight, exhibited by these birds,

is very limited. On the other hand, the feed sparing effects of loss in body weight although amounting to a few gm. only per week is maintained for so many weeks that the cumulative effect becomes greater than that due to gain in body weight.

The advantage of the smaller over the heavier birds is well illustrated. It will be seen that the total feed 69.1 lb. required for all purposes by the Leghorns is about $7\frac{1}{2}$ pounds smaller than the bare maintenance feed of

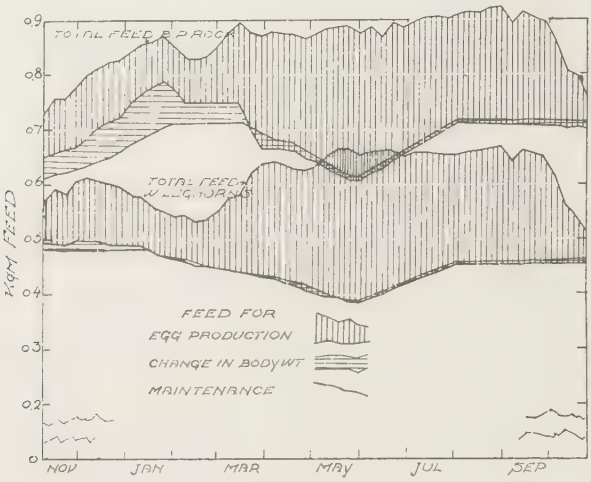

FIGURE 3.

the Rocks 76.5 lb., and the 33.4% difference in total yearly feed requirement is mainly brought about by the 41.5% difference in maintenance feed. Figure 3 shows that only during May and June does the total feed for the Leghorns reach and overlap the maintenance feed of the Rocks.

FEED REQUIREMENTS UNDER PEN CONDITIONS

The demonstrated difference in feed required by large and small birds when maintained in cages is so important that it was felt advisable to amplify the evidence for their validity by an investigation of the corresponding requirements under pen conditions.

During the years 1930–31 and 1935–36 the data necessary for this purpose were collected on 5 pens with 15 birds to the pen and 4 pens each of 50 birds, all of the Barred Plymouth Rock breed. In addition we obtained data on two pens of 50 White Leghorns in each pen. It was obviously desirable to make the comparison between light and heavy birds on the basis of performance treated previously in this analysis. The feed consumption of all pens were therefore adjusted to the body weights, production levels and changes in body weight formerly employed. These adjustments were made by applying the mean of our standards for maintenance and the partial regressions for egg production and changes in body weight. The observed feed consumptions and adjusted feed consumptions are shown in Table 4.

TABLE 4.—DIFFERENCE IN YEARLY FEED CONSUMPTION FOR LIGHT AND HEAVY BIRDS

Year	No. birds	Breed	Total feed consumption per bird per year			
			In pens			In cages
			Observed	Adjusted	Mean	Mean
			lb.	lb.	lb.	lb.
1935–36	50	S.C.W.L.	70.9	80.8		
	50	S.C.W.L.	72.3	83.5	82.2	69.1
1930–31	15	B.P.R.	71.5	101.0		
	15	B.P.R.	74.9	103.5		
	15	B.P.R.	73.4	108.4		
	15	B.P.R.	77.7	106.4		
	15	B.P.R.	71.2	106.7		
	50	B.P.R.	98.6	109.8	105.7	96.8
1935–36	50	B.P.R.	90.8	103.4		
	50	B.P.R.	98.2	109.3		
	50	B.P.R.	89.0	102.8		
Percentage difference in mean feed consumption between Leghorns and Rocks					25.0%	33.4%

It is immediately noticeable that feed consumption has been considerably heavier in the birds maintained under pen conditions. Also that the increase has been heavier in the Leghorns than in the Rocks with the result that the difference in mean annual feed consumption between the two breeds has been narrowed down from 33.4% in cage birds to 25.0% in pen birds.

The increased feed consumption under pen conditions will undeniably be of some economical significance since nearly all birds are being thus maintained. We therefore wished to inquire into the reasons for these increases. Obviously the much more unrestricted activity of penned birds must make certain claims to energy consumption. In addition the house wherein the caged birds were accommodated was gently heated during the winter, whereas the birds in pens were subjected to the ordinary temperatures prevailing in poultry houses throughout the years. Such a difference, provided the pen temperature drops sufficiently low, induces a heavier feed consumption for heating purposes in penned birds during the winter season.

During the winter of 1932–33 data were obtained on four pens of Barred Plymouth Rocks with 50 birds in each pen. Two of these pens were heated and two were left unheated, this being, as far as possible, the only difference in treatment. The mean features of this experiment, as far as they concern this analysis, are presented in Table 5.

TABLE 5.—EXPERIMENTAL DATA ON HEATED AND COLD CONDITIONS

Conditions	Mean body weight	Mean gain in body weight	Mean production	Mean feed consumption
	gm.	gm.	gm.	gm.
Heated pen	2822	78.4	6128	22,261
Cold pen	2806	90.6	6548	24,002

When the mean feed consumption for the heated pens is adjusted, by means of the partial regression coefficients, for differences in production and gain in body weight, it is found that this group would have consumed an average of 22,644 gm. The saving in feed, presumably due to heat alone is therefore 24,002 − 22,644 = 1358 gm. per bird.

These pens were heated for 147 days and the mean weekly difference in feed consumption is therefore 64.7 gm. The average of sampling errors for weekly feed consumptions in caged birds was found to be 18.8 gm. As this is the only pertinent measure of variability in our possession we applied it in a test of significance which showed p to be of the order of 0.01. The observed difference in mean feed consumption between the two conditions is therefore a highly significant one. The mean temperature for the heated pens was 54.6 ± 0.34° F. and for the cold pens 40.6 ± 0.69° F. The significant difference in mean feed consumption was therefore due to a lowering of the mean temperature 14° F. below the one which is generally regarded as approximately the lower limit for maintenance of normal basal metabolism in fowl. This difference due to heat alone, *i.e.*, 1358 gm. applied to a body weight of 2814 gm. The means of the two body weight curves presented in Figure 2 are 1995 gm. for Leghorns and 3094 gm. for Rocks. Assuming a linear regression the differences due to heat alone for these two body weights would be 964 gm. and 1492 gm. respectively. Deducting these amounts from the differences between caged and penned birds we may calculate approximately the energy required for increases in metabolism due to the above mentioned cooling and increase in activity. These calculations are presented in Table 6.

Table 6.—Utilization of energy for heating and activity under ordinary pen conditions

Breed	Feed consumed per bird per year						Feed consumed per kgm./24 hr.		Consumed available calories per kgm./24 hr.	
	Adjusted total pens	Total cages	Difference		In 147 days due to heat	In 358 days due to activity	due to heat	due to activity	due to heat	due to activity
			Pens	Cages						
	lb.	lb.	lb.	gm.	gm.	gm.	gm.	gm.	cal.	cal.
S.C.W.L.	80.8		11.7	5300		4336	3.3	6.1	10.5	19.3
	83.5	69.1	14.4	6523	964	5559	3.3	7.8	10.5	24.7
B.P.R.	101.0		4.2	1903		411	3.3	0.4	10.5	1.3
	103.5		6.7	3035		1543	3.3	1.7	10.5	5.4
	108.4		11.6	5255		3763	3.3	3.4	10.5	10.8
	106.4		9.6	4349		2857	3.3	2.6	10.5	8.2
	106.7	96.8	9.9	4485	1492	2993	3.3	2.7	10.5	8.6
	109.8		13.0	5889		4397	3.3	4.0	10.5	12.7
	103.4		6.6	2990		1498	3.3	1.4	10.5	4.4
	109.3		12.5	5663		4171	3.3	3.8	10.5	15.2
	102.8		6.0	2718		1226	3.3	1.1	10.5	3.5

In a previous paper (*loc. cit.*) we presented evidence to show that caged birds in most instances require 40 available calories per kgm./24 hr. for all maintenance requirements above basal metabolism. The last column of Table 6 would indicate that under conditions of unrestricted activity in pens with males present this required amount will be raised to an average

of 62.0 for Leghorns and 47.8 for Rocks per kgm./24 hr. Furthermore, the higher metabolic level induced by low temperatures during winter months claimed, under our experimental conditions an average of 10.5 additional calories per kgm./24 hr. for 21 weeks. In view of the characteristic difference in behaviour of the two breeds it is not surprising that Leghorns on the average burn up more energy due to greater activity. However, the wide variations demonstrated within the Plymouth Rock pens in their calorific requirements for activity are somewhat surprising, although differences may possibly exist in the degree of activity exhibited collectively by the

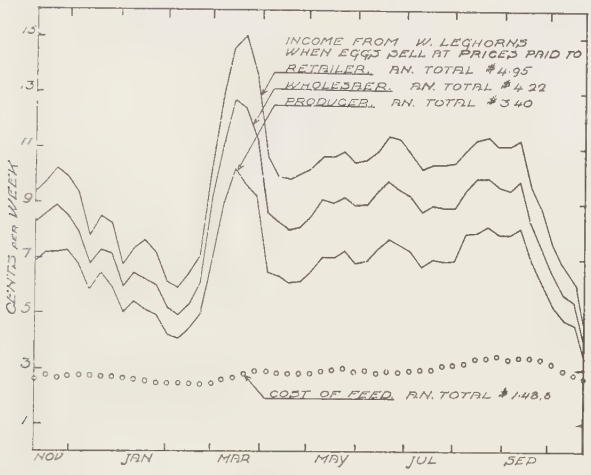

FIGURE 4.

birds in different pens of the same breed; still this does not seem a very probable explanation. It should therefore not be lost sight of that due to the procedure in calculation practically all experimental error has been accumulated in this one small fraction. We therefore feel that determination of this variability is of little value. On the other hand, the calculations of Table 6 do establish as a physiological fact the narrowing down of the difference in annual feed consumption between Leghorns and Rocks under pen conditions to about 25% from the 33% difference previously demonstrated for the same breeds when maintained in cages.

COST OF FEED

Through the courtesy of commercial distributors of poultry feeds we obtained the ruling retail quotations for mash and scratch grain through the year November 1, 1935 to October 31, 1936, for locations throughout the Dominion. For the courtesy thus extended to us we wish to record our sincere appreciation. These prices were so combined as to represent an equal mixture of mash and grain and to give one series of 51 prices throughout the year representative of the average price level for the whole of Canada. Applying this series of prices to the feed requirements of caged birds in corresponding weeks we were able to calculate the two cost-of-production curves shown in Figures 5 and 6. The total cost per hen for the year amounted to $2.09 for the Barred Plymouth Rocks and

to $1.49 for the White Leghorns. Thus there is a difference in the cost of the observed production of 60 c. between breeds. The difference in the mean body weights here employed at the end of the year amounts to 1100 gm. or 38.8 ounces. The price per pound of the birds when sold for

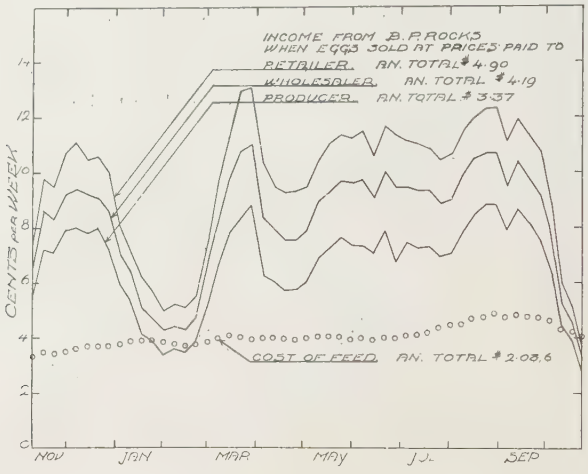

FIGURE 5.

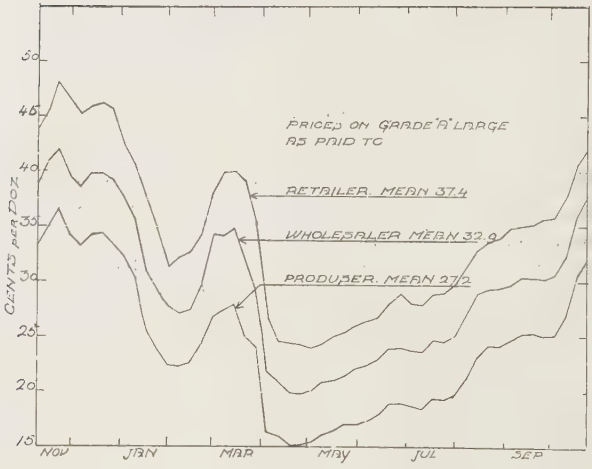

FIGURE 6.

meat would therefore have to be 27.3c. per lb. if the heavier birds were to come out even on the year's operation, which probably, is highly unlikely. In penned birds the total feed cost per hen for the year would be $1.77 and $2.29 for the two breeds respectively with a difference between breeds of 52c.

INCOME

We have then, accounted for the feed cost of egg production in the average domestic hen. In the following remarks we propose briefly to treat the probable average income from well kept Canadian pullets, and so clarify the problem of average profit over feed cost in such Canadian poultry flocks as come within the scope of this analysis.

For this purpose we collected the quotations of egg prices as paid to producer, wholesaler and retailer throughout the laying year from November 1, 1935 to October 31, 1936. These three terms, *i.e.*, paid to producer, wholesaler and retailer, employed throughout this paper should be understood to signify the prices which the producer would obtain in case he sold his eggs at wholesalers' or at retailers' purchasing quotations or direct to consumer at retailers' selling quotations.

Included in this survey were quotations at 9 representative points, namely, Vancouver, Edmonton, Regina, Winnipeg, London, Quebec City, St. John, Charlottetown and Halifax. The points chosen were thought to be those most nearly representative of the true relationship between producer to consumer price levels throughout the country. Thus Montreal prices were excluded because they are largely speculative curb market prices, and London, Ontario was preferred to Toronto as a quotation point because the latter is more a dumping ground for a wide surrounding area. For each point nine quotations were secured for each week through the year, that is, prices on Grades A large, A medium and pullet eggs as paid to consumer, wholesaler and retailer, were obtained for 51 weeks for each of the 9 points. From these data 9 prices were calculated for each week representative of the unweighted mean Canadian price level throughout the year. For the sake of brevity seasonal trend in these prices is illustrated by the three curves in Figure 4. These curves represent the average Canadian price paid to producer, wholesaler and retailer, for Grade A large eggs throughout the year.

In passing, a brief analysis of average price levels in the various localities may be in order. Table 7 lists the average prices paid to consumer and retailer throughout the year.

TABLE 7.—AVERAGE PRICE TRENDS PER DOZEN EGGS OF "GRADE A LARGE" THROUGHOUT THE LAYING YEAR 1935–36 IN NINE TYPICAL CANADIAN LOCALITIES

	Prices paid per dozen		Per cent of consumer price received by producer
	To producer	By consumer	
Vancouver	25.5	33.0	77.3
Edmonton	19.2	31.4	61.1
Regina	20.3	31.2	65.1
Winnipeg	20.0	33.8	59.2
London, Ont.	22.1	32.8	67.4
Quebec City	28.1	37.5	74.9
St. John	27.0	37.4	72.2
Halifax	28.6	39.0	73.3
Charlottetown	24.2	33.3	72.7
Weighted mean			67.9

It will be seen that, as far as producer prices are concerned, Central Canada including Ontario is decidedly a poorer district than both east and west. Furthermore, when it is considered that feed prices are as low in British Columbia as those throughout the Prairie Provinces, presumably due to elevator facilities at tidewater, and that the percentage of consumer money received by the producer is the highest in the Dominion,

this province is outstandingly the favoured locality for egg production. The high egg prices ranging throughout the Eastern Provinces are to some extent offset by high feed prices. On a general average poultrymen receive slightly better than two-thirds of the retail price of eggs.

Applying the weekly average prices for Canada to the weekly production of the various sizes of eggs experienced in our two contest populations we arrive at the curves of gross income presented in Figures 5 and 6. The whole situation of net income over feed cost per bird from well kept pullets under presumably average Canadian conditions may be briefly presented as in Table 8.

TABLE 8.—NET INCOME OVER FEED COST

	Light birds			Heavy birds		
	Gross income	Gross income less feed cost		Gross Income	Gross income less feed cost	
		Cages $1.49	Pens $1.77		Cages $2.09	Pens $2.29
	$	$	$	$	$	$
Prices paid to—						
Retailer	4.95	3.46	3.18	4.90	2.81	2.61
Wholesaler	4.22	2.73	2.45	4.19	2.10	1.90
Producer	3.40	1.91	1.63	3.37	1.28	1.08

From the "net income" here presented deductions should be made for overhead and the cost of pullets at the beginning of the laying year. Likewise mortality should be taken into account as well as revenue from poultry meat at the end of the year.

All data herein presented rest on the assumption that well kept pullets in this country produce on the average for the year at the rate of about 52%. In the past, several attempts have been made to calculate at exactly which level of production gross income will just cover the cost of feed. However, on closer observation such deductions appear of very limited utility. In the first place such a balance will undoubtedly leave the poultryman with a net loss due to overhead expenses and cost of rearing the pullets. In the second place, with the percentage of production as the constant, profits will, as shown, be dependent on the three variables, namely price levels on eggs, and on feed and body weight of birds, which latter involves differences in volume of maintenance feed. Any calculation of this sort will therefore be to such an extent a specific case that its general applicability becomes meaningless. However, as an illustration it may be of interest to show a calculation using the values employed throughout this analysis. We therefore solve equations of this type:

$$\begin{matrix} 1 & 2 & 3 & & 4 & & 5 & 6 & 7 & 8 \end{matrix}$$

$$\frac{y}{12} \times \left(3.40 \div \frac{186}{12}\right) = (22.752 \times 4.84) + (y \times 46 \times 4.84)$$

where y is the number of eggs and therefore (1) the unknown number of dozen eggs, (2) a total revenue shown in Table 8, (3) the experienced

number of dozen eggs, (4) the known maintenance feed as shown in Table 3, (5) and (8) the average price per 1000 gm. feed and (7) the average amount of feed per egg in gm. By solving we arrive at the number of eggs required to cover the cost of feed experienced under the apparent average Canadian conditions during the laying year of 1935–36.

TABLE 9.—EGGS REQUIRED TO COVER TOTAL FEED COST OF BIRDS MAINTAINED IN CAGES

Prices paid to	Light birds, No. eggs	Heavy birds, No. eggs
Producer	69	104
Retailer	45	69

In order to cover overhead and cost of raising the pullets to maturity additional numbers of eggs will be required.

CONCLUSIONS

1. Difference in feed cost of various sizes of eggs amount to 1.756 gm. or 4.3% feed per egg for every one ounce per dozen difference in the size of eggs.

2. Due to the volume of feed required to maintain body weight the smallest possible bird giving maximum production of standard sized eggs is, economically, the most desirable unit.

3. On the evidence here presented small and large mature birds of the breeds herein analysed have about equal chances to lay large or small eggs. This relationship holds between breeds as well as within a breed. Size of egg in the mature bird is therefore genetically and environmentally uncomplicated by body size.

4. In the immature bird ovary and oviduct are apparently developed proportionately to the body size as in such birds egg size shows an important correlation to body size.

5. The average production for Canadian well kept birds of the White Leghorn and Barred Plymouth Rock breeds appears to be at the rate of about 52% for the year.

6. Total annual feed consumption per bird of the White Leghorn and Barred Plymouth Rock breeds as herein represented appear to be about 69 and 97 lb. respectively when the birds are maintained in cages. When similar birds are allowed the freedom of a pen about 82 and 106 lb. will be required respectively.

7. Calculations of net revenue over cost of feed have been presented for the two breeds under conditions obtaining in cages as well as in pens. The more favourable balance shown by birds of the Leghorn breed is solely due to the smaller feed cost of maintaining the comparatively lower body weight characteristic of this breed.

8. On the average throughout Canada the producer receives 67.9% of the price paid by consumers for eggs.

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REFERENCE

1. Bird, S. and Sinclair, J. W. A study of the energy required for maintenance, egg production and changes in body weight in the domestic hen. Sci. Agr. 19 : 542-550, 1939.